MODELS and INNOVATIONS: ARCHAEOLOGICAL and REGIONAL APPROACHES TO GUANAJUATO, MEXICO

edited by

EZRA B.W. ZUBROW

& ANDREW R. WILLARD

G
972:41
ZUB

MODELS AND INNOVATIONS:
ARCHAEOLOGICAL AND REGIONAL APPROACHES
TO GUANAJUATO, MEXICO

edited by

Ezra B. W. Zubrow
Andrew R. Willard

Department of Anthropology
Stanford University

G
972.4101
MOP

Dedicated to two families:

Emilio, Berta and Emilito Bejarano

and Alexis and Marcia Zubrow

© 1974 by the Board of Trustees of
The Leland Stanford Junior University
All rights reserved

Printed in the United States of America

DIRECCION DE BIBLIOTECAS
UNIVERSIDAD DE GUANAJUATO

PREFACE

This monograph serves multiple purposes. First, the editors feel that with increasing publishing costs and increasing demands from publishers for introductory books which sell to big audiences, there are only a few outlets for technical monographs. Yet since it is through technical papers that the field advances, the publication and distribution of monographs should not be totally sacrificed to economic necessity.

Second, the editors feel that it is particularly important to publish the results of archaeological research. Archaeology is a destructive science. Once artifacts have been removed from the earth, they can never be replaced into the same context. Without published reports the information is lost to other specialists and to the general public. We therefore feel responsibility to report on Stanford's archaeological research in Mexico as rapidly as possible. This report presents new theoretical models and archaeological data which these models purport to explain. In addition, it reports on the successful use of new techniques for procuring archaeological information.

Third, this monograph partially fulfills the legal obligation which the director of the research, the Department of Anthropology, and Stanford University contracted with the Federal Government of Mexico. Ezra Zubrow, as the director of Stanford's archaeological research in Mexico, and as a representative of the Department and University, was generously granted a permit to do archaeological research in Guanajuato by the Federal Government of Mexico[1]. This permit, which was obtained from the National Institute of Anthropology and History under Article 31 of the Federal Law on Archaeological, Artistic and Historical Monuments, requires the responsible parties to submit to the National Institute of Anthropology and History a variety of monthly, annual and final reports. This monograph is one of these reports.

Fourth, this monograph represents an international, cooperative effort of both professional archaeologists and students from the United States and Mexico. Both professionals and students were involved in all stages of this research--the development of the research design, the writing of the proposals, the field execution of the research, the writing and the final editing of the monograph.

---

[1] Support for this field research project was provided under grants from the Research Development Fund, Stanford University, and Latin American Studies, Stanford University.

The monograph consists of seven articles. They are: 1) The Archaeology of Cañada de Alfaro, Guanajuato, by Ezra Zubrow; 2) Agricultural Patterning, by Ezra Zubrow, 3) Agricultural Distribution in Guanajuato, by Thomas Sagehorn; 4) Archaeology and the Portable Refraction Seismograph, by Elizabeth Skinner; 5) The Relationship between Labor and the Size of Sites in Guanajuato, Mexico, by Elizabeth Skinner; 6) Analysis of Surface Survey Data, Cañada de Alfaro, by Emily Wilkens; and 7) A Growth Model of Subsistence Cultures, by Keith Kintigh.

The research and this monograph represent a large group effort and thus numerous individuals and institutions need to be thanked. Three individuals must be particularly noted: Señor Emilio Bejarano, the regional archaeologist for Guanajuato and Queretaro and the associate director of the research program, was indespensible in every research, logistic, and bureaucratic phase of Stanford's archaeological program; Señor Chavez Morado, the director of the Museo Ahlondiga de Granaditas of Guanajuato, was particularly kind in making the facilities of the museum available and providing laboratory and storage space; Mary Lou Johnson-Schwartz was the translator par excellence and was not only an important member of the research team, but a remarkable facilitator who made the contact between two cultures easily adaptable. Other residents of Mexico who provided numerous services included: Benjamin Brown, Patsy and Earl Jones, Doug Mellis, A.K. Desmond, Joanne Coyne, and Tita Braniff. We were fortunate to be able to assist four students from the University of Veracruz with their archaeological education and to receive the benefits of their experience.

The following residents of the United States were members of a variety of research design, field research, and data analysis teams: Margaret Taylor, James Feurstein, Carl Hagenmeir, Robert Bone, Christine Hastorf, James Slater, Barbara Solomon, Amos Zubrow, John Justeson, Keith Kintigh, Robert Clemen, Elizabeth Skinner, Andrew Willard, and Nancy Botti. Drafting was done by Margaret Taylor, A.K. Desmond, Nancy Botti, Andrew Willard, and Kippy Nigh. Artist's reconstruction of sites were done by Doug Mellis. Field photography was the responsibility of Joanne Coyne and James Slater, while photographic processing in the United States was the result of the patient efforts of Tom Sagehorn.

Finally, I wish to thank the following institutions: Stanford University's Research Development Fund, Center for Latin American Studies, Chiapas Project, Center for Research in International Studies, the Office of the Dean of Undergraduate Studies, and the Provost's Funds for Computation, all provided funds for various aspects of this research. In addition, the Department of Anthropology, the Computer Center and the Linear Accelerator all provided equipment and consultation. The National Institute of Anthropology and History and the Museo Ahlondiga de la Granaditas generously provided information, staff, and supplemental support, which included: field vehicles, office, laboratory, and storage space, as well as photographic laboratories and exhibit space. The Government of the state of Guanajuato generously allowed us to use the Treasury Department's IBM 360 computer. The staff of Centenal helped us find and made copies of numerous aerial photographs and maps as did the Departmento Hydraulico. The United States Geological Survey provided us with ERTS satellite imagery of Guanajuato; since these space observations were multi-spectral, they also provided us with the equipment to overlay the various photographs to produce a composite image. International Imaging Systems of Mountain View allowed us to use their electronic pseudo color density image slicing equipment in order to obtain the maximum information from our aerial and satelite photographs. The Ejido of Cañada de Alfaro allowed us to work on their lands and in their fields as well as graciously taking us into their homes and into their hearts.

Ezra Zubrow
Andrew Willard

TABLE OF CONTENTS

The Archaeology of Cañada de Alfaro:
A Regional Description
Ezra B.W. Zubrow 1

Agricultural Patterning
Ezra B.W. Zubrow 51

Agricultural Distribution in Guanajuato
Thomas Sagehorn 67

Archaeology and the Portable Refraction Seismograph
Elizabeth Skinner 85

The Relationship Between Labor and the Size of
Sites in Guanajuato, Mexico
Elizabeth Skinner 147

Analysis of Surface Survey Data, Cañada de Alfaro
Emily Wilkins 159

A Growth Model of Subsistence Cultures
Keith Kintigh 191

THE ARCHAEOLOGY OF CAÑADA DE ALFARO:
A REGIONAL DESCRIPTION

Ezra B.W. Zubrow

Introduction

During the summers of 1972 and 1973 I directed the Guanajuato Prehistoric Regionalization Project in Cañada de Alfaro, Guanajuato, Mexico. It was a joint archaeological expedition of Stanford University and the National Institution of Anthropology and History. The latter was represented by the Associate Director, Emilio Bejarano, who is the Director of the Regional Center for Archaeology for the states of Guanajuato and Queretaro. This article is a descriptive report of the results and an introduction to the volume.

Objectives

The project had numerous general objectives. First, we wished to do a regional study using the archaeological data as a central theme. It was clear from the outset that we could not limit ourselves, however, only to archaeological data. Therefore, one will find references in this paper and in the other papers in this volume to ethnographic, environmental, economic and other data. The second objective was to test a series of alternative, formal models. Models were developed to examine modern agricultural patterning and distribution as well as the relationships among prehistoric labor, site size, and site function. In addition, there was a continuing examination of models of economic growth and development in order to understand the processes of changing prehistoric regionalization.

There is a major gap in our knowledge of the prehistory of Guanajuato. No complete archaeological survey or generalized chronological sequence of the state exists. There has not been a complete excavation of a single site in all of Western Guanajuato, an area of approximately 15,250 square kilometers. It has been estimated that there are more than 5,000 archaeological zones within this western area. In short, this non-nuclear, marginal region of Mexico has been virtually ignored by archaeologists with the exceptions of important work being done by a limited number of scholars such as Tita Braniff, Emilio Bejarano, and Shirley Gorenstein. The latter two are presently undertaking a major project in the southeastern part of the state which will do much to correct the situation. Thus, the third objective was to complete a systematic site survey of a limited area within western Guanajuato and to begin the excavation of a series of sites with the purpose of helping to develop an accurate ceramic sequence and site typology. Fourth, we attempted to develop new techniques for interpretation of archaeological materials. We developed a methodology for utilizing the refraction seismograph to determine the interior structure and stratigraphy of a variety of structures and applied it in archaeological zones. We used a variety of remote sensing imagery to provide additional information. This included ERTS satellite photography, aerial photography, and pseudo color density image slicing, as well as analytical techniques for information processing.

These general objectives were partially fulfilled by obtaining precise data from the following direct field objectives:

1. The archaeological field objectives were:
   a. The exploration of the archaeological zone Cañada de Alfaro.
   b. A systematic surface survey in order to map the locations of all the sites within the zone.
   c. The stratified sampling of the surface material from each mound within the zone.
   d. The mapping and photographing of each mound and the collection of a wide range of information about each mound on site survey forms.
   e. The test excavation of a limited number of single and multi-component sites to help determine the site dimensions, the composition of sites, the number of components, and the nature and degree of cultural homogeneity of artifactual material.
   f. Artistic reconstructions of a limited number of sites.
   g. The analysis of aerial photographs to locate other archaeological zones and sites.
   h. The centralized collection of information from other archaeologists on other known archaeological zones in the region.
2. The objectives of the environmental field studies were:
   a. The collection of geological data and information through geological surveys and reports to obtain stratigraphic and topographic information of the zone and surrounding areas.
   b. The collection of biological materials for ecological information about potential carrying capacity, standing crop and productivity within the zone.
   c. The analysis of aerial photographs for information on agricultural distribution.
   d. Large scale agricultural field surveys to determine the patterning of agricultural fields.
   e. An ethnographic resource survey to determine the distribution of natural resources used in agricultural manufacturing processes in modern subsistence economies in the area.
   f. Palynological sampling from sites to determine the prehistoric vegetation component.
3. The objectives of the field laboratory were:
   a. The recording, cleaning and analysis of the surface and excavation artifactual collections from each mound.

b. The clarification of the chronological sequence of Cañada de Alfaro.
c. The clarification of the structural and architectural remains in particular sites of the Cañada.
d. The examination of previously predicted site locations from analytically determined patterns.
e. The analysis of the biological and agricultural materials.

Location

If one divides the map of Mexico in half, both vertically and horizontally, the point of intersection is very close to Guanajuato. The state is located on the central Mexican plateau about 3 to 4 hours north of Mexico City by car. It is bordered by the states of Queretaro, San Luis Potosi, Aguascalientes, Jalisco, and Michoacan. Most of the articles in this monograph concern aspects of Guanajuato geography. This article will emphasize the area surrounding Cañada de Alfaro and secondarily the area nearby San Miguel de Allende. Cañada de Alfaro is a small village, an ejido, and a hacienda located four kilometers east of Leon, the largest city in Guanajuato and approximately 35 kilometers northwest of the city of Guanajuato, the capital of Guanajuato. More precisely, the archaeological zone and the village is located at 101° 36.3' west, 21° 8' north (see Figure 1). The archaeological zone is located on the lands of the Ejido Alfaro, the Ejido San Pedro de las Hernandez, the Predio San Miguel, and upon the private property of Maria Solis Segura. The zone belongs administratively to the municipality (county) of Leon. It is 340 kilometers from the nearest ocean, the Pacific, and 240 kilometers northwest of the famous site of Tula, as the bird flies (see agricultural patterning).

The archaeological zones surrounding San Miguel de Allende are a hundred kilometers southeast of Leon and Cañada de Alfaro. They are located between 100° 40' and 100° 52' west, and 20° 45' to 21° north (see Figure 2). Zones are about 150 kilometers from Tula and about 330 kilometers from the closest points on the Atlantic and Pacific seacoasts.

General Topography, Hydrology, and Geology

Guanajuato lies between the two major chains of mountains which make up the backbone of Mexico, the Sierra Madre Occidental and the Sierra Madre Oriental. The bulk of the state consists of large mountain chains interspersed with large alluvial valleys. A traveler often has the impression that he is standing in a large flat bowl surrounded by high mountains. Several of these large valleys in the western and southern part of the state are interconnected and make up what is called the Bajio. These valleys are justly known as the breadbasket of Mexico.

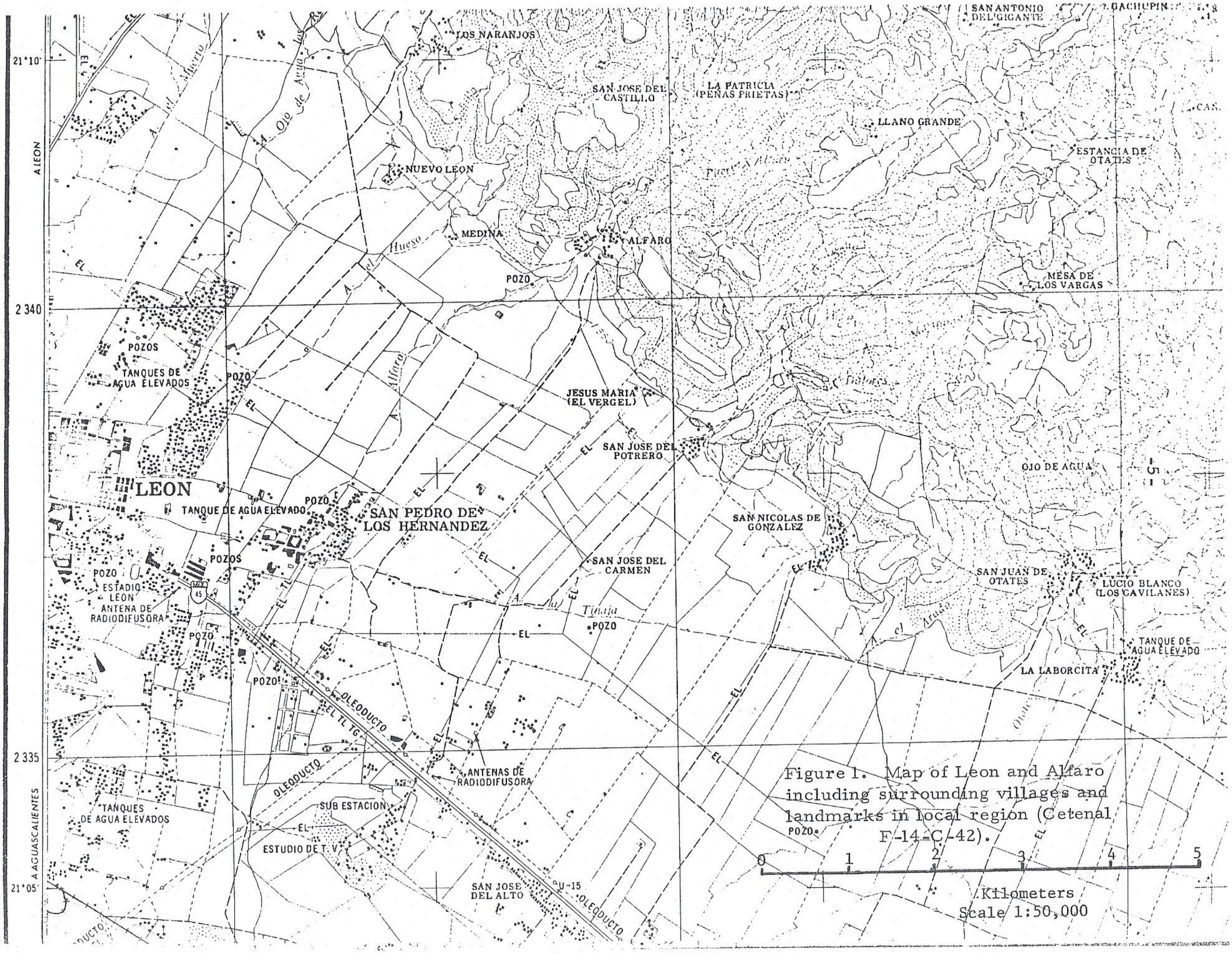


Figure 1. Map of Leon and Alfaro including surrounding villages and landmarks in local region (Cetenal F-14-C-42).

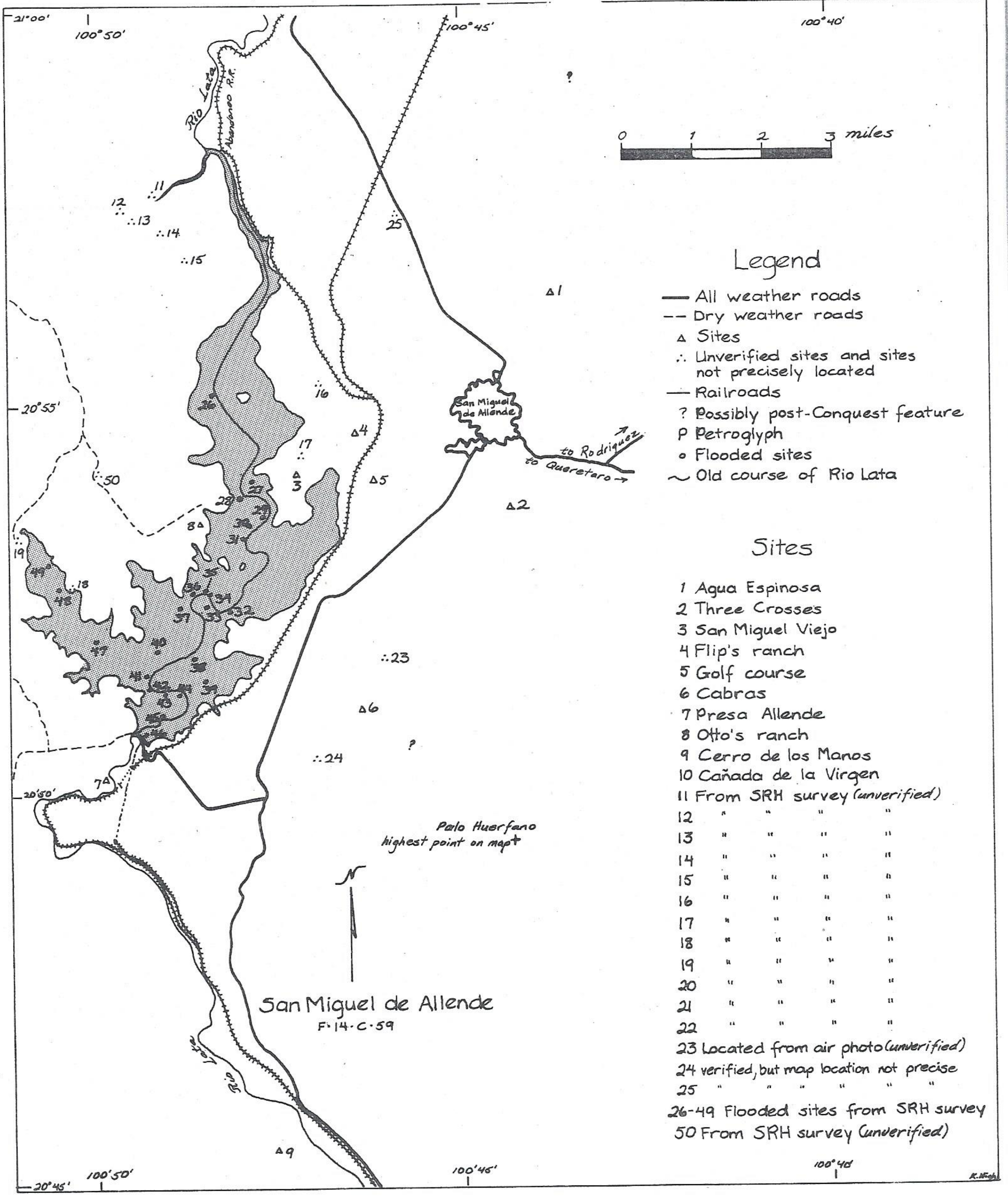


Figure 2. Archaeological zones near San Miguel de Allende.

Figure 3 is an ERTS satellite photograph of an area 186 kilometers by 186 kilometers (115 miles by 115 miles) taken from an altitude of 917 kilometers (570 miles). It covers the area surrounding the city of Leon and a considerable area to the north and west. The cities of Lagos, Leon, Silao, and Guanajuato are marked on the photograph. The heavy, irregular black lines which have been drawn on the photograph demarcate the large valleys, including part of the Bajio mentioned above. Most of the modern cities and prehistoric sites that are known are located within or upon the margin of these large valleys. The archaeological zone of Cañada de Alfaro lies where the mountains meet the valley east of Leon. These valleys usually show the remnants of two or three river terraces as large individual hills or series of hills. A careful examination of Figure 3 will show the mountains and the drainages between these large alluvial valleys. The small, very irregular white shapes on Figure 3 are lakes.

The Bajio Valley near Leon, Silao, and the Cañada de Alfaro archaeological zone ranges in altitude from 1,750 meters (5, 740 feet) near Silao to 1800 meters (5,904 feet) near Leon, and at the base of the mountain range reaches 1850 meters (6,068 feet). The mountains consist of stepped foothill ranges which slowly rise from 2,000 meters (6,560 feet) to 2,100 meters (6,888 feet) to 2,200 meters (7,216 feet) and 2,300 meters (7,544 feet) as one moves east. Peaks reach as high as 2,500 meters (8,200 feet) at Mesa Gallo and Mesa Moreno, and 2,850 meters (9,348 feet) at Mesa la Cuatralba.

The state of Guanajuato has a reasonably complex hydrological configuration. The state makes up part of the Federal government's hydrological zone 12. The most important drainage is the basin of the river Lerma in the southern part of the state. It consists of a series of natural (Lago de Yuriria) and artificial lakes, such as the one behind Solis Dam. A set of secondary rivers, including the Rio Laja in the San Miguel area, the Rio Irapuato, the Rio Turbio, and the Rio Guanajuato have considerable drainages in their own right and create their alluvial valleys. The state has primarily a dichotomic drainage pattern with a major exception (see Figure 4). The area immediately surrounding Leon, Irapuato, Salamanaca, and Celaya have clear rectilinear drainage patterns. This clearly demarcates the Bajio from other valley areas. As one moves south from Leon to Irapuato and east to Celaya, the number of channels per square kilometer increases from an average of .07 to .14 to .25. If one compares the area just west of the Cañada de Alfaro archaeological zone to the area just east of the zone, a change from rectilineal to dichotomic drainage is reflected in a slight decrease numerically in the channels. This decrease, .07 to .06 channels per square kilometer, also denotes that one is moving into a mountainous configuration.

Figure 3. ERTS Satellite photograph including major cities, contour lines demarcating valley areas and the Leon Silao transect. (NASA, Evos Data Center)

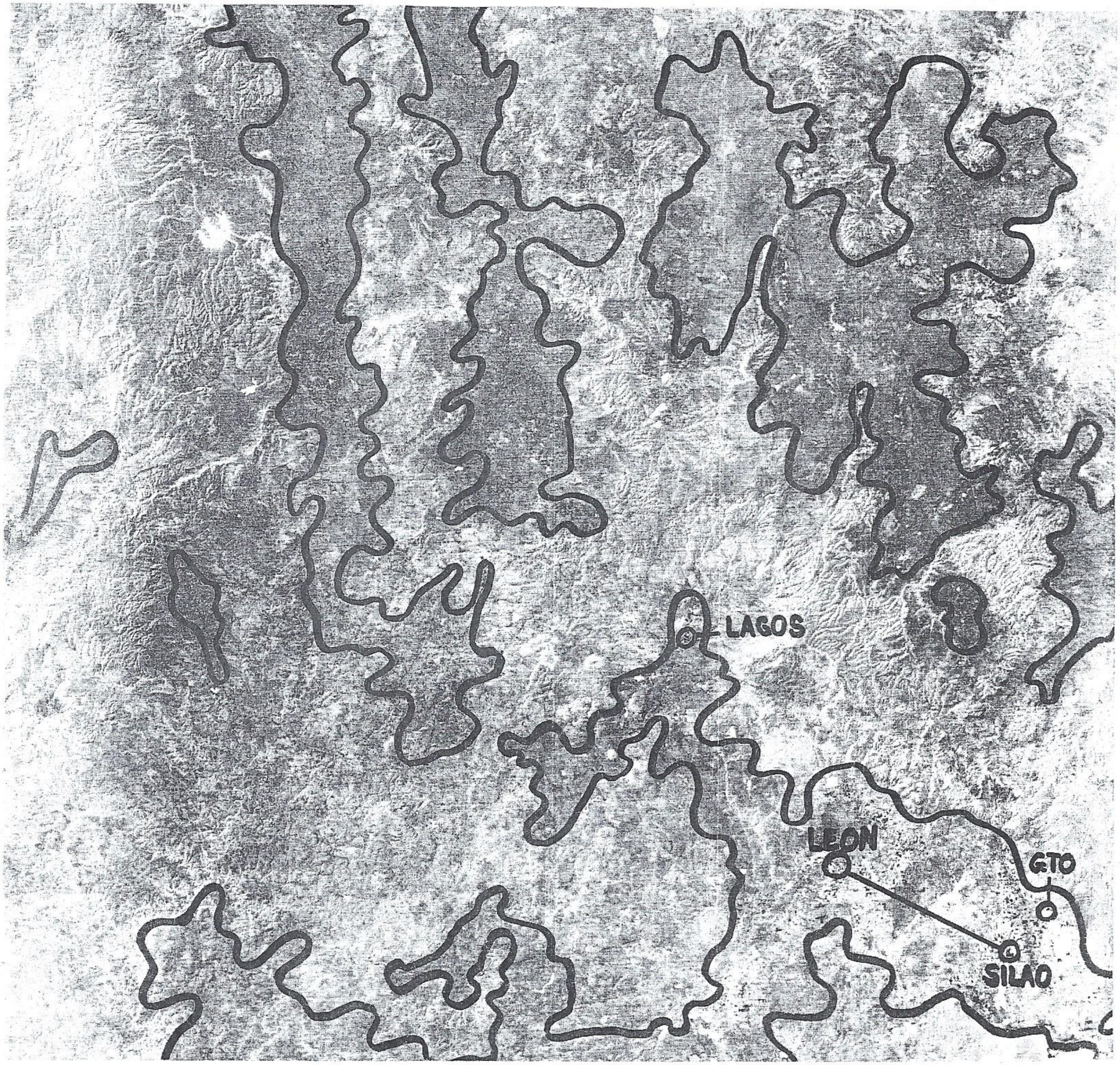
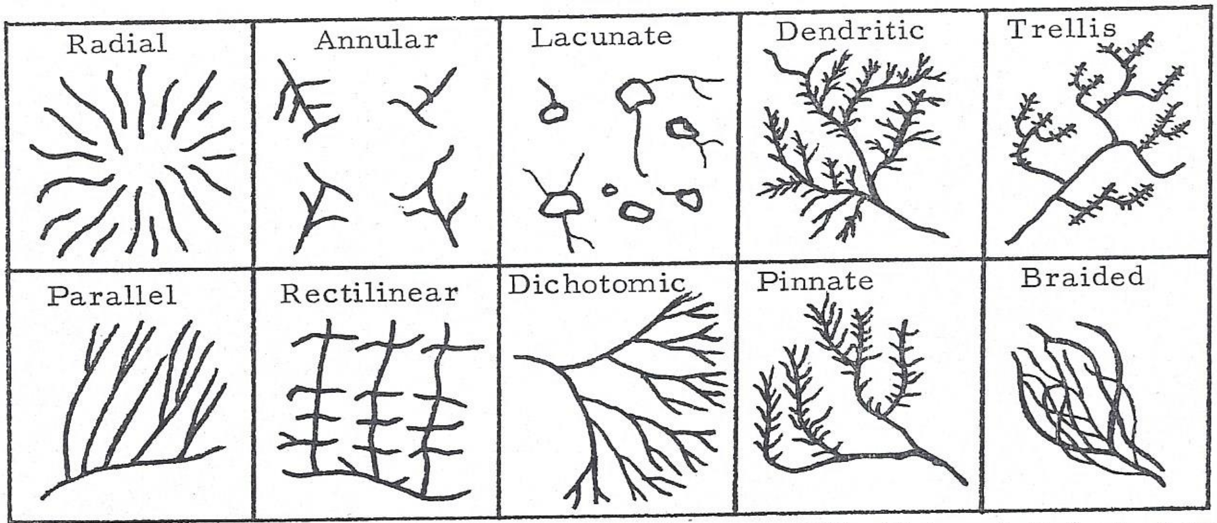


Figure 4
Common Drainage Patterns



After John A. Howard, Aerial Photo-Ecology, p. 209, Faber & Faber, London.

The area surrounding the archaeological zones in San Miguel de Allende also follow a dichotomic drainage pattern. However, in this area the dichotomic pattern is in combination with a parallel pattern. This area has approximately .09 channels per square kilometer. All of the above figures are based on samples of 400 square kilometers.

The geology of the large valleys, including the Bajio, is straightforward. They consist of an alluvium made up partially from the valley beds themselves and partially from the mountains. As one moves closer to the mountains, increased amounts of vasicular basalt are found. The Bajio consists of middle Cenozoic extrusives (Cmv) derived from lava flows, Oligocene andesites, basalt and Miocene rhyolites. The andesites are usually found stratigraphically lower than the rhyolite deposits. The mountains which border the Bajio in the east near Leon, and which are partially incorporated into archaeological zones, consist of the lower Cenozoic intrusives (Cii) principally from the lower Tertiary. It also includes deposites of Grustaceous materials. As one moves further east into the higher mountains and the mining areas, that is closer to the city of Guanajuato, the Cenozoic intrusives give way to a complex pattern of Mesozoic Triasic deposits (TR). These consist of agglomerates and calcareous deposits as well as black and green volcanics. These mountains have been and continue to be exploited for silver mining which dates back in the area to the 16th century. The silver ore is sulphur and sulphur-antimony and is found in pockets or enclaves. Profound exploitation has taken place over four centuries and the mine shafts reach 300-500 meters.

As one continues to move east from the city of Guanajuato and drops out of the mountains into the large alluvial valley surrounding San Miguel de Allende and its archaeological zones, the general valley geology returns to middle Cenozoic extrusives (Cmv). Just south of the town, however, there exists a component of Cenozoic volcanics (Csc) derived principally from basalt lavas, pyroclastic agglomerates and the numerous undercones of the recent Pliocene.

General Demography, Biology, and Agriculture

Guanajuato is a mixture of small, very productive agricultural regions such as the Bajio and large marginal zones located primarily in the mountains. It is our contention that prehistorically it was a marginal area except in localized zones. Although there have been some changes in the environment since prehistoric times, a quantitative understanding of the modern biosphere is useful for analytical purposes. For example, considering the state of agricultural technology, one may validly use modern demographic and agricultural statistics for the extreme upper limits that no prehistoric population could exceed.

Guanajuato, according to the 1970 census, had a population of 2,270,370 people (1,139,123 males and 1,131,247 females) in an area of 30,589 square kilometers for a density of 74.22 people per square kilometer. Only four other Mexican states out of the total of 32, including the Federal District of Mexico have higher population densities. The 1.56 percent of the surface area of Mexico which is Guanajuato supports 4.71 percent of the Mexican population. The 1,800,345 hectares under cultivation according to the 1968 agricultural census represents 1/3 of the entire land area of the state. If one removes the urban population (localities of 5,000+), the density drops to 38.17 persons per square kilometer. Adjusting for the amount of land under cultivation, the density for agriculturally productive land is approximately 12.91 people per square kilometer.[1] These three figures (74.42, 38.17, 12.91) bracket the range of densities calculated for early Neolithic populations by Allen for Southwestern Anatolia (24.3 to 1.8), by Forge in New Guinea (34.7) and Zubrow in the Southwestern U.S. using floral productivity figures (60.5 - 27.7). Although the densities are similar, the productivity of the state is much higher than would be expected from a Neolithic population.

How is this agricultural product distributed by crop? Table 1 compares the agricultural acreage and production of Guanajuato and Mexico in 1968. Three generalizations may be drawn from this table.

---

[1] One should note the slight inaccuracy built into this 12.91 figure by the combination of the 1968 agricultural census with the 1970 demographic census.

First, production is lower (an average 3.3 tons per hectare) in Guanajuato than for all of Mexico (an average 4.2 tons per hectare). This marginality may be re-stated in other words that Guanajuato has 6.4 percent of the total land in Mexico under cultivation but only produces 5 percent of the total crop tonnage. If we could exclude the Bajio from these figures, it would show even more marginal situation. Second, a large number of Mexican crops are not grown in Guanajuato. Table 1 reports all crops in the agricultural census for Mexico. 38 percent (26) of these crops are not grown in the state. Many of these are of course tropical. However, for even the major staples such as corn and beans, the state is just able to hold its own. It produces 5 percent and 7 percent of the total Mexican tonnage of corn and beans on 6 percent and 7 percent respectively of the total land in these crops. Third, one may examine the crops for which the environment in Guanajuato is particularly well adapted. By the term well adapted we mean either the amount or the area under production make up a significant proportion of the total Mexican cultivated tonnage area (over 30 percent). These crops are garlic, onions, green tomatoes, and strawberries. They are relatively unimportant as a subsistance base, making up less than 2 percent of the state's agricultural land and less than 4 percent of Guanajuato's total agricultural product. These specialized crops make up less than 1 percent of the total Mexican land under cultivation and less than 1 percent of the total agricultural product.

In order to obtain a more accurate understanding of the biosphere in the Cañada de Alfaro archaeological region, a three part research design was used. The first part analyzed the patterning of agriculture; the second, the distribution of agriculture. They are reported in the next two articles in this monograph. The third part consisted of the collection and analysis of biological materials within the archaeological zone. The expedition began a systematic sampling study to analyze the floral biomass. The archaeological zone was divided into three sampling strata. The first strata consisted of the agricultural fields. The second strata was the non-cultivated areas of the valley portions of the archaeological zone. The third strata consisted of samples taken in the canyons of the mountains bordering the archaeological zone. Five nested quadrats (each consisting of a 30 meter square, 3 meter square and a 1 meter square quadrat) were randomly located within each strata for a total of 15 nested quadrats or 45 individual quadrats. The thirty meter square quadrats were analyzed for plants of tree size, the three meter square quadrats for plants of bushes and shrub size, and the 1 meter square quadrats for plants of grass size. Christine Hastorf identified all the plants in each quadrat by popular name and Linnean name. In addition, she counted the number of plants and weighed them for biomass.

Table 2 presents the number of plants grouped by genera and quadrat for each of the 15 samples in the 3 strata. The popular names are given

Table 1. Agriculture of Guanajuato and Mexico, 1968

PRODUCT	Area of Guanajuato under cultivation in product (in Hectares)	Total area of Mexico under cultivation in product (in Hectares)	Guanajuato area as percentage of Mexican area in product	Amount of product grown in Guanajuato (in tons)	Amount of product grown in Mexico (in tons)	Amount of Guanajuato product as percentage of Mexican product
Corn	490,000	7,250,000	7	440,000	8,400,000	5
Beans	130,000	2,100,000	6	65,000	1,000,000	7
Wheat	55,000	820,000	7	170,000	2,150,000	8
Rice	0	230,000	0	0	615, 000	0
Potatoes	4,000	45,000	9	55,000	440, 000	13
Cotton seed	0	890,000	0	0	1,150, 000	0
Soybeans (for salad oil)	0	315, 000	0	0	210, 000	0
Peanuts	6, 500	80, 000	8	10, 000	100, 000	10
Cartamo	500	115, 000	.4	1, 000	145, 000	1
Copra	0	86, 600	0	0	185, 000	0
Cocoa oil	0	21 , 000	0	0	26, 000	0
Castor oil plant	0	9, 500	0	0	6, 000	0
Linseed	1,000	19, 000	5	1, 300	19, 000	7
Soybeans	0	140, 000	0	0	27, 500	0
Tomato	8,000	52, 000	15	150,000	634, 000	23
Garlic	3,000	7, 200	41	18,000	35, 000	51
Sweet potato	3,200	15, 000	21	26,000	115, 000	22
Onions	6,000	19, 000	32	44,000	125, 000	35
Peas	1,000	8, 000	13	2, 500	14, 000	18
Dry chiles	1, 600	21, 000	7	2, 400	22, 000	11
Green chiles	4, 200	34, 000	12	37,200	155, 000	24
String beans	400	7, 000	6	2,000	15 , 000	13
Beans	1, 000	54, 000	2	1,000	45, 000	2
Jicama	300	5, 000	6	3, 000	40, 000	7
Lentils	1, 500	6, 300	24	1, 000	4, 600	21
Green tomatoes	2,100	7,500	28	14,800	33, 000	45

Cotton	0	89,000	0	0	3,000,000	0
Cane sugar	800	459,233	.1	56,000		
Barley	20,000	286,000	7	60,000	325,000	19
Cocoa	0	82,320	0	0	30,430	0
Oats	1,000	95,000	1	1,000	76,000	1
Coffee	0	285,000	0	0	174,000	0
Sissal-hemp	0	212,000	0	0	164,000	0
Tobacco	0	39,000	0	0	71,000	0
Vanilla	0	600	0	0	330	0
Alfalfa	25,000	160,000	16	1,600,000	9,000,000	19
Sorghum	180,000	1,000,000	18	414,000	2,400,000	19
Garbanzo	50,000	215,000	23	33,000	160,000	21
Strawberries	5,000	7,600	66	60,000	91,000	66
Melons	1,000	22,000	5	12,000	220,000	5
Papaya	0	9,900	0	0	198,600	0
Watermelon	1,000	27,300	4	9,000	230,000	4
Avacado	600	13,350	4	8,400	160,000	5
Plums	0	980	0	0	11,750	0
Peaches	2,840	9,570	3	15,600	105,000	15
Guava	150	9,300	2	2,600	126,000	2
Fig	40	1,000	4	300	9,000	3
Lime	140	3,500	4	1,000	30,000	3
Lemon	110	30,200	.4	800	277,400	.3
Mango	0	24,400	0	0	426,700	0
Apple	100	23,740	.4	1,100	169,400	1
Oranges	0	135,000	0	0	1,571,000	0
Nuts	0	870	0	0	4,700	0
Pecans	70	5,000	1	250	11,000	2
Olives	50	3,140	2	45	12,650	.3
Palm coconuts	0	86,600	0	0	1,007,000	0
Pears	70	3,000	2	800	30,700	3
Bananas	0	35,000	0	0	455,000	0
Bananas (roatan)	0	33,000	0	0	323,000	0
Pineapple	0	10,250	0	0	286,000	0
Grapefruit	0	1,100	0	0	13,000	0
Grapes	700	16,600	4	4,400	133,000	3

(Table 1 continued)

PRODUCT	Area of Granajuato under culti-vation in product (in Hectares)	Total area of Mexico under culti-vation in product (in Hectares)	Guanajuato area as percentage of Mexican area in product	Amount of product grown in Guanajuato (in tons)	Amount of product grown in Mexico (in tons)	Amount of Guanajuato product as percentage of Mexican product
Acorn	0	3,800	0	0	25,000	0
Apricot	50	600	8	780	9,000	9
Country plums	0	6,450	0	0	57,250	0
Dates	0	820	0	0	8,000	0
Red pomegranate	75	500	15	1,700	7,700	22
Alpiste	150	4,500	3	200	4,500	4
Forage beet	100	2,200	5	3,000	50,000	6
Total Amount	1,008,345	15,811,523		3,330,000	66,329,741	

Total area of Guanajuato under cultivation as percentage of total area of Mexico under cultivation--6.4%

Total amount of agricultural products of Guanajuato as a percentage of total amount of agricultural products of Mexico -- 5.0%

Table 2. Ecological Samples in Cañada de Alfaro (Number of plants per genera per sample)

	Agricultural Field Samples (Valley Floor)					Non Agricultureal Field Samples (Valley Floor)					Canyon Samples				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
30 Meter sample (tree size plants)															
Nopal (Cactaceae)		5				3	5	19	6		17	16		11	6
Mesquite (Leguminosae prosopis)		1	6			1	5	3	6		2	4		12	5
Granhino (Aschpia daceae)		1	2			7	15	9	2						
Casaquate (Convolvulaceae)											5				
Organ Pipe (Cactaceae)											2				
Capitana (Compositae)												8			16
Yubasanisa (Compositae)														17	
Unknown											1				
3 Meter sample (shrub size plants)															
Nopal (Cactaceae)							1	2	1			1	1		
Mesquite (Leguminosae prosopia)						4	2		1	1	1	1	1		
Granhino (Aschipiadeceae)															1
Casaquate (Convolvulaceae)												1		1	
Capitana (Compositae)						3		2	1	1					1
Yubasanisa (Compositae)							2	2	9	2				2	
Corn (Solanoceae zea maize)	27	21	28	23	17										
Bean (Leguminosae)	1	5	6	1											
Calavasa (Curcuribitaceae)	2														
Torito (Martyniaceae)		4													
Espatia (Verbenaceae)									1		3	5			
Venenillo (Apocynaceae)										1					
(Chenopodaceae)											7				
(Labitae)											1				
(Spandaceae)												1			
(Euphorbiaceae)												1			
Unknown															3

(Table 2 continued)

	Agricultural Field Samples (Valley Floor)					Non Agricultural Field Samples (Valley Floor)					Canyon Samples				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1 Meter Sample (grass size plants)															
(Compositae)	3	16	7	5	2	101					390			15	80
(Leguminosae)	76	15		13	196		303	38	11	23		15	150		
(Graminaceae)		33				228	1408	660	90	320	205	66	122	123	10
(Verbanaceae)		1													
(Scrophulariaceae)		1					43	6	1		113	2	2	17	5
(Euphorbiaceae)			10									3			14
(Loasaceae)			5												
(Cyperaceae)				8	5										
(Oxalidaceae)				16											
(Portulaceae)															
(Umbelliferae)							60	182	70	35		111	75	25	3
(Rubiaceae)								128	73	45				8	
(Violaceae)								11	4						
(Ranunculaceae)								31	50						
(Convolvulaceae)									2					15	
(Malvaceae)										2					
(Comositae)										2					
(Cruciferaceae)										2				2	
(Crassalaceae)										1				100	2
(Commelinaceae)											2				
(Lythraceae)												16			
(Labiatae)														8	
(Linaceae)														7	
(Amaranthaceae)														2	2
(Boragenaceae)														18	
(Fouguieriaceae)															14
Unknown		25	2			25						10			9
Weight of plants in 1 meter sample (in grams)	33.0	29.5	50.1	40.9	32.1	56.6	125.2	108.9	59.4	89.9	275.1	31.3	66.2	234.7	69.4

for tree size and shrub size plants in addition to the generic name. For the grass sized plants, only the generic name is given but the total biomass per sample is also shown. Several generalizations may also be drawn from this table. 1) The diversity of plants clearly increases inversely to their size in all the ecological strata. Thus, as one moves from tree size plants to grass size plants, the average number of known varieties per sample for the agricultural strata increases from 1.0 (tree size), 2.2 (shrub size), to 3.4 (grass size). Similarly, for the non-agricultural strata and the canyon strata, the figures are 2.4, 3.4, 5.8, and 2.6, 3.2, 6.8 (see Figure 5-a). 2) The diversity of the flora increases as one moves from the agricultural to non-agricultural strata and from the valley to the canyon strata for plants of all sizes. Thus, the average number of known varieties per sample for tree sized plants increases 1.0, 2.4, 2.6 (agricultural, non-agricultural, and canyon samples respectively). Similarly, for shrub sized plants the figures are 2.2, 3.4, 3.2, and grass sized plants 3.4, 5.7, 6.8 (see Figure 5-b). 3) The amount of biomass in the 1 meter square quadrats increases as one moves from the agricultural to the non-agricultural strata and from the valley to the canyon strata. The average amounts of biomass in grass sized plants per quadrat, are 37.1 grams, 87.8 grams, and 135.3 grams respectively. 4) Agricultural products make up approximately 65 percent of all known plants in the 3 meter square quadrats. The ratio is 9 to 1 corn to beans. On the average, 2.6 corn plants are planted per meter square. In the 1 meter quadrats where agricultural products are immature, they make up 5 percent of the known plants. There are 7.0 bean plants planted per meter square.

In short, the general ecological picture for agriculture which may be drawn for Guanajuato is a picture primarily of marginality, one in which the land is similar to the average agricultural land in Mexico for the production of the staple crops and where production is proportional simply to size of land and agriculture. It is an area in which agriculture is a significant part of the biosphere (5 to 65 percent), but one in which there is more biomass in the non-agricultural and canyon zones than in the agricultural zones. Indeed, with larger biomasses, greater diversity of plants and thus stability, the non-agricultural and canyon zones must be considered an important resource for the prehistoric populations even after agriculture was developed.

Figure 5a. Diversity of Plants by Plant Size.

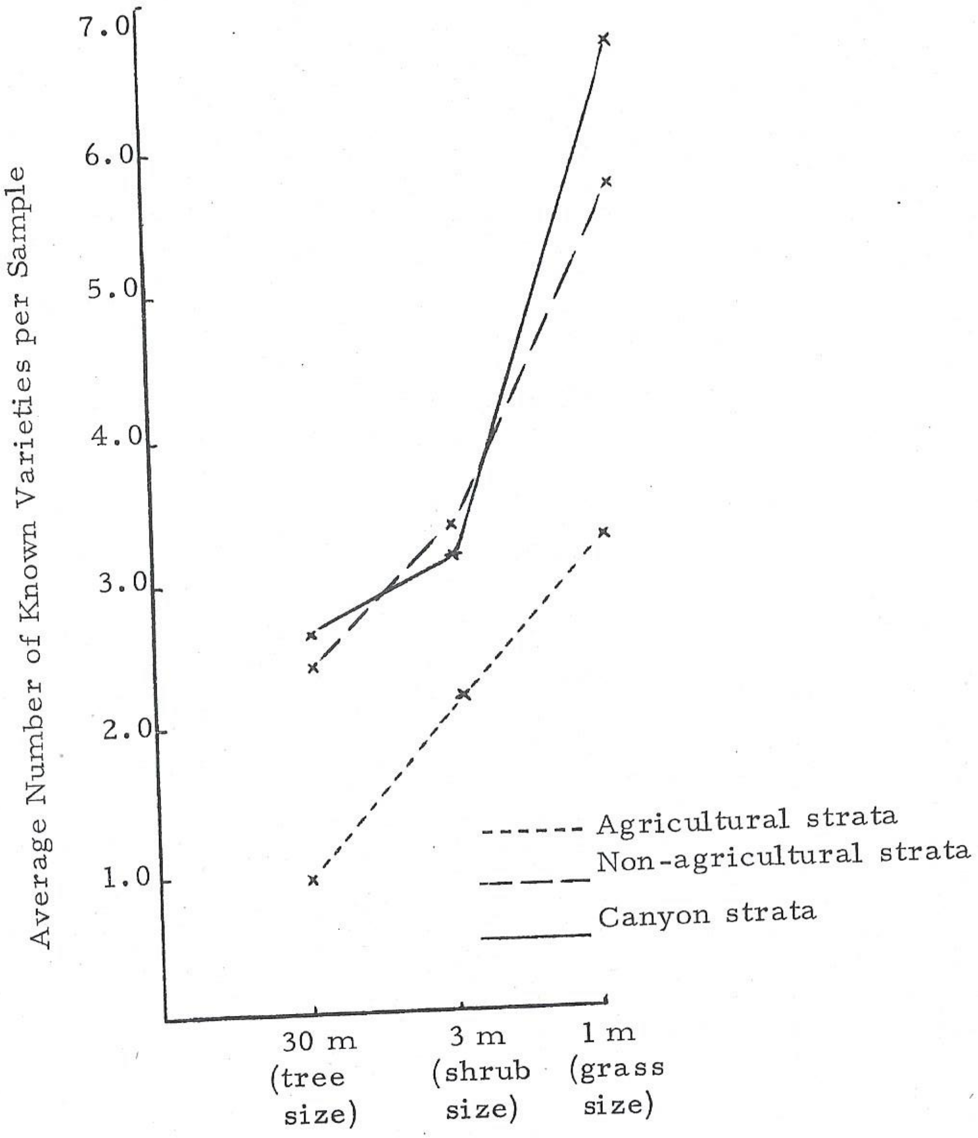
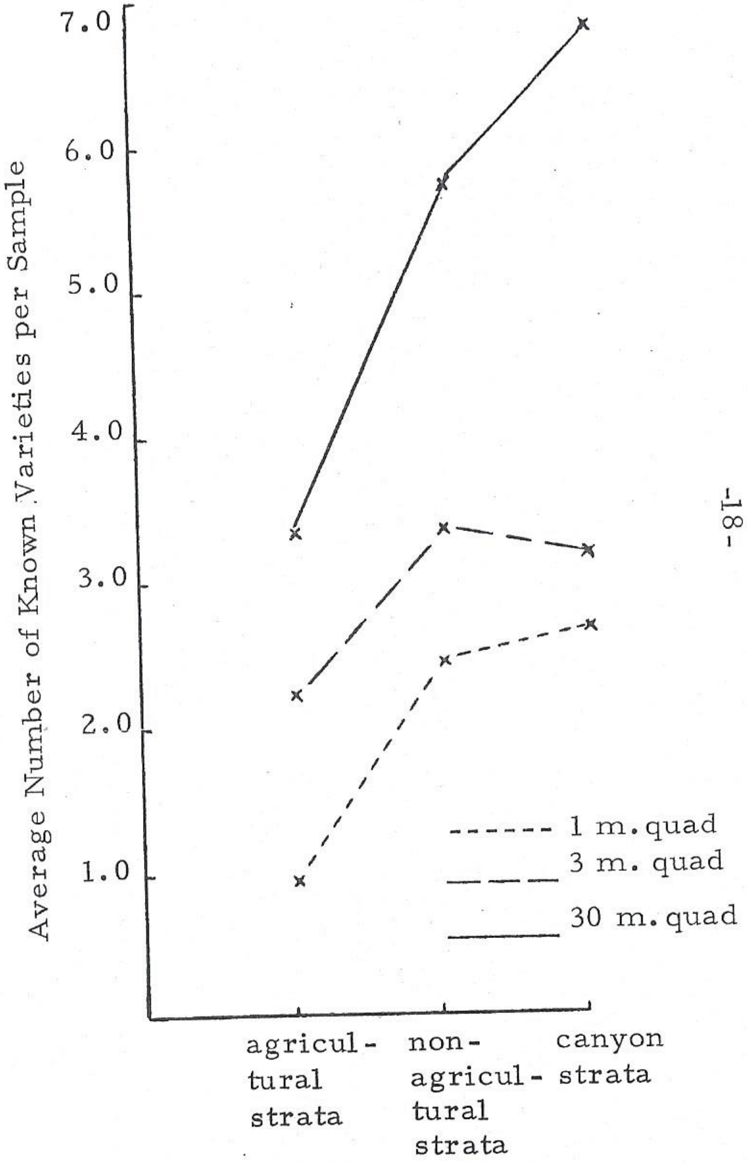


Figure 5b. Diversity of Plants by Ecological Strata.



Present State of Knowledge of the Prehistory of Guanajuato

Archaeological interest has begun to focus on northern and western Mexico only during the last 30 years and with the exception of Porter's early work, it is only during the last 10 years that significant archaeological research has begun to take place in the state of Guanajuato. The Lerma River, which flows through southern Guanajuato, serves archaeologists as a boundary line for the northern limits of "Nuclear Mesoamerica" as defined by Kirchoff. During the pre-Columbian era, nuclear Mesoamerica included several populations which shared many cultural traits. Most of Guanajuato north of the Lerma River is considered a part of marginal Mesoamerica, a region characterized as being sparsely populated by hunting and gathering peoples with occasional agricultural settlements in river valleys. What is interesting to note about marginal Mesoamerica is, first, that the boundaries are relatively stable but do not always remain at the same location over time. Thus, Kelley notes a frontier with the Chichimecs between 100 BC and 1000 AD as far north as southwestern San Luis Potosi. This frontier could not be maintained and by the sixteenth century had retreated to the south and west. Second, under stress economic and cultural change appears to occur rapidly in these marginal areas. For example Armillas discussing nearby Michoacan claims that the cultures are short lived and isolated up to the advent of the Tarascan Empire.

As far as I am aware, no early man sites located in Guanajuato have been either excavated or published. Litvak-King has described a Middle Formative culture in the lower Balsas basin of Michoacan. Fluted points have been found in Jalisco and Pleistocene fauna exist at Chupicuaro (see below) and along Lake Cuitzeo.

Within the Preclassic Period (500 BC - 200 AD), a culture known as Chupicuaro (400 - 200 BC) flourished in a large area of southern Guanajuato and what is today the northern part of the state of Michoacan, especially along the Lerma River. From the evidence found at the Chupicuaro site (during Porter's excavations done in 1946-48) and from the Jerecuaro (a Guanajuato Chupicuaro site reported by Matos Moctezuma in 1968), it is apparent that the Chupicuaro culture closely paralleled that of the Valley of Mexico during the Preclassic period. Perhaps the Valley of Mexico was even surpassed if the quality, technique and variety of ceramic styles are used as a criteria. During the Classic period (200 - 800 AD) nuclear Mesoamerica expanded to the north. By the end of Teotihuacan IV, in the late classic, it had been enlarged over the Bajio and into the northwest to cover the area bounded by the 1800 meter and 2250 meter contours. Guanajuato and the other areas of marginal Mesoamerica incorporated in this expansion seem to have developed small ceremonial centers. Ceramics show local developmental trends with certain influences from Teotihuacan. Marginal Mesoamerica does not seem to have ever developed the cultural elements which prevailed at this time in the south -- the cult of Tlaloc, Quetzalcoatal, and other major dieties, the use of the Mesoamerican calendrical system, urban ceremonial centers, and many other traits which Kirchoff lists.

During the Post Classic period nuclear Mesoamerica again contracts to its Lerma River boundary and nomadic hunting and gathering tribes move into areas where the ceremonial centers are deserted. During the Classic and Post Classic, it is probable that Guanajuato, and particularly the Lerma River Valley was a major route for the movement of goods and people. It is intermediate between the west coast, the Northern Frontier (i.e. the states of Zacatecas, Durango and Jalisco), and the Valley of Mexico, which served as an economic and cultural hub for most of Mexico in precolumbian times.

One theory recently proposed by archaeologists working in the area is that not only was Guanajuato a migration and trade route but that as a border area it was actually a sort of military frontier with a series of fortifications to protect the civilizations of the south from the "barbaric," warlike nomads of northern Mexico who were seen as a threat to the agriculturalists. During the summers of 1972 and 1973, work was being carried out in Acambaro in southern Guanajuato by Columbia University under the direction of Dr. Shirley Gorenstein. A structure was explored on a hilltop site which she felt was a possible fortification.

Other recent archaeological research done in eastern Guanajuato includes the work of Beatriz Braniff, who has worked almost exclusively in the states of Guanajuato and San Luis Potosi, in an attempt to set up ceramic chronologies for these areas and correlate them with the valley of Mexico. Her work has provided a valuable framework for the study of ceramics in this project. Figure 6 is an attempt to look at the chronological relationships between Guanajuato and the surrounding areas of Michoacan and Zacatecas -- Durango. It represents a synthesis derived from the work of Chadwick, Kelley, Braniff, Gorenstein, Willey and others. It should be noted that at best it is a tentative chronology which outlines temporal relationships between cultural sequences, ceramic phases and archaeological sites. It must be considered tentative because it oversimplifies an extremely complex geographically specialized situation and includes considerable speculation.

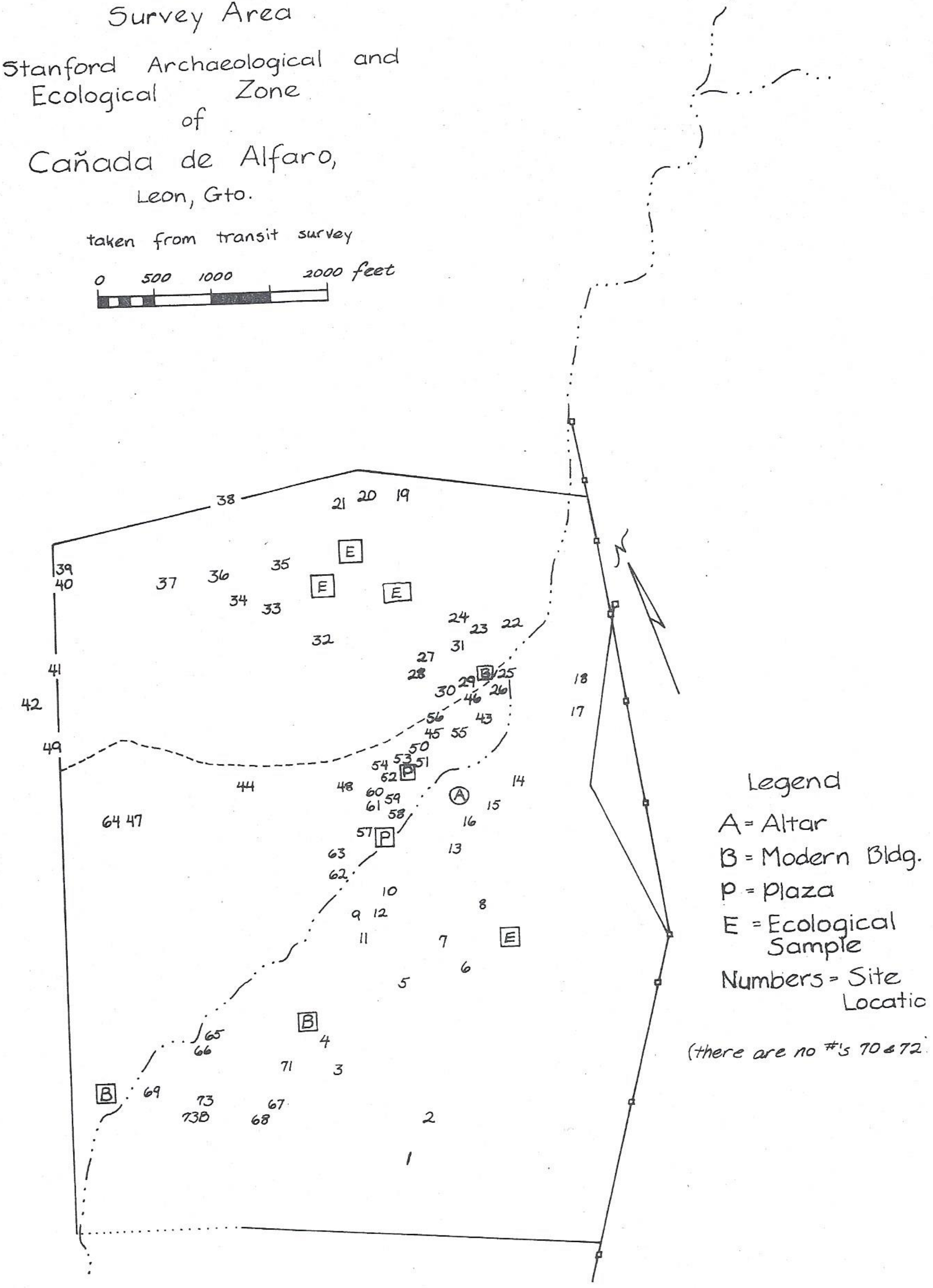
The major works done in the entire marginal Mesoamerican region concerning specifically the study of settlement patterns are the ongoing studies of J. Charles Kelley. He has done extensive work in the states in Zacatecas, Durango and Jalisco on the Northern Frontier.

The Cañada de Alfaro zone is simply one link in a chain of interconnected clusters of sites. One of the neighboring clusters was

	Zacatecas		Durango	Guanajuato	Michoacan			Central Mexico
	Cultural Sequence	Ceramics Phases	Sites	Sites	CULTURAL SEQUENCE	CERAMICS PHASES	SITES	CULTURAL SEQUENCE
1500					Tarascan			Aztec IV
								Aztec III
	Chalchiuites	Calera	Schroeder				Tzintzuntzan	Aztec II
						Cojumatlan El Poche		Chichimac Aztec
1000		Rio Tunal	Schroeder		Tarascan			
		Las Joyas Vesuvio	El Vesuvio					Tula-Mazapan (Aztec I)
								Coyotlatelco
						Chapala	Cojumatlan Bay	
		Retoño Ayala						
500		Calichal	Calichal Atotonilco			Jiquilpan	Jiquilpan	
		Alta Vista	Alta Vista		Delicias			Teotihuacan III
		Canutillo	Cerrito dela Corfadia	CAÑADA DE ALFARO				
								Teotihuacan II
0								
				Jerecuaro Chupicaro	Chupicaro	Late Chupicaro	Zinapecuaro Zacapu Pureparo Jacona	Teotihuacan I
						Early Chupicaro		Cuicuilco-Ticoman
500					El Opeño	El Opeño	El Opeño	
						Infiernillo		
1000								Tiatilco

Figure 6. Sequences in Guanajuato and Surrounding Areas
(All of these sequences are actually far more complicated but have been simplified for ease of presentation)

Figure 7. The Distribution of archaeological sites in the Cañada de Alfaro zone.



systematically explored and partially excavated by Emilio Bejarano in 1971. A circular structure somewhat reminiscent of Toate, Jalisco was explored and stratigraphic test pits were dug. The final report on this zone, known as Ibarilla (see Figure 1), has yet to be published. It is particularly interesting, in the context of Mexican archaeology, that circular structures are found in this region as they are uncommon in most of Mexico after the Preclassic except in the Huasteca, a region on the northeastern coast, and along the Northern Frontier.

Archaeological Research in Cañada de Alfaro

After visiting various known sites in central Guanajuato (Tarimoro, Agua Espinosa, Tierra Blanca, Ibarilla) in order to familiarize the research group with known sites, materials, and lithic and ceramic taxonomies, archaeological research was begun in Cañada de Alfaro. This zone was chosen for intensive study because it cross-cut two major ecological zones as well as numerous michrohabitats. Initially there was an informal exploration which consisted of attempting to delineate where the approximate outer limits of the zone were located. Once these limits were determined, the research group turned to the systematic exploration of the zone.

Systematic Exploration of the Zone

The zone was surveyed in the following manner. The total universe was defined and divided into two areas bisected by the river. The outer boundaries of the first area were then surveyed with the transit. A line of ten people -- spaced approximately twenty meters apart -- was then set up, and this line was moved back and forth between the boundaries. The line began at the SW corner and searched a 200 meter strip until it reached a boundary, then it turned and surveyed the next strip. This process continued until the entire area was covered and was then repeated for the second area. In short, it was a systematic field survey with 100% coverage. When a prehistoric mound or activity area was located by the survey team, it was tagged with surveyor's tape. Each site was then relocated by a mapping team which surveyed with a transit the exact location of each site as shown on the map of the zone (Figure 7). The total area surveyed was 24.5 square kilometers in which were found 72 sites. This constitutes a total 2.9 sites per square kilometer. Of these, 18 sites are in area one and 54 sites are in area two. They range in size from 720 square feet to 80,435 square feet with an average size of 10,169 square feet. Within this group there are 48 mounds, 24 lithic and sherd scatters, 6 plazas, 1 ballcourt. There are 24 circular and 12 rectangular mounds as well as a variety of miscellaneous shaped sites.

This large diversity implies either that the archaeological zone was probably the result of multiple occupations or a reflection of multiple activity areas. The map clearly shows that the distribution of mounds is non-random. Rather there is, in area 1, a generally linear pattern between site 3 and site 18. This is complicated by a major cluster of sites consisting of numbers 5, 6, 7, 8, 9, 10, 11, which I have labelled cluster 1. In area 2 there are 5 more clusters. Cluster 2 is located at the top of a hill and is composed of sites 19, 20, and 21. This cluster which includes a ballcourt, a site with a plaza, as well as two prehistoric roads, ranges in elevation between 1952 meters and 1960 meters. Cluster 3, the central cluster of the zone, consists of sites 22, 23, 24, 30, 31, 43, 45, 46, 48, 50 to 59, and 60 to 63. This cluster is partially located on a large terrace. Sites 22 and 43 have large interior plazas. Cluster 4 is sites 22 to 26; cluster 5 -- 32 to 37; and cluster 6 -- sites 3, 4, 65 to 69, 73, 73b.

The reality of the clusters are calculated by comparing average inter-cluster site distance to average intra-cluster site distance.

For example, the average distance between sites in cluster 3 is approximately 100 meters. The average distance between sites in cluster 5 is approximately 135 meters, the average distance, however, between the sites in cluster 3 and the sites in cluster 5 is 600 meters or approximately a ratio of 1:6. Similar results are obtained from the other clusters. If communication is a partial function of distance, it is clear that site communication within clusters is greater than site communication between clusters.

If one examines the site distribution from south to north, it follows a general pattern of an upside down V. The central cluster (# 3), makes up the vertex and the NE leg. It is also clear that the site density increases as one moves from south to north. This major site cluster is not surrounded on all sides by the other clusters. Instead the other clusters are on the southeast and southwestern sides and are not on the northern side of the central cluster.

Stratified, Systematic "Quadrant Defined" Surface Sampling of Each Mound

As each mound was discovered, a standard site form was completed and a systematic quadrant defined sample was taken from the surface of each site. First, the center of the site and the total area of the site were determined. The total area was sub-divided into three sampling strata, the top, side and border areas of the mound. A ten percent sample of each strata was obtained from five randomly selected surface squares. In order to obtain a representative sample, and also to insure that the sampling was not clustered, four of the five squares were randomly located under the constraint that one fell within each of the four compass quadrants (0-89, 90-179, 180-269, 270-359). The fifth square was randomly located anywhere within the strata. We thus sampled the full potential variation. Each square was located on the site map and then a complete surface collection of all the cultural material within each square was made. All of the collected materials from each square were kept in bags labelled by site number, square number, type of material, date of collection, and name of the recorder. The total area collected from the 72 sites was 77,337 square feet or an average of 1,106 square feet per site. There were 41,927 ceramics and 9,088 lithics collected. Only 5 of the 72 sites (19, 32, 33, 38, 40) have more lithics than ceramics. The lithic to ceramic ratio ranges from 18:1 to 1:29 with a total ratio of 1:5.

If one calculates the lithic to ceramic ratios for clusters 1 to 6 as percentages, the values are 37%, 88%, 18%, 11%, 52%, 18%. There are two groups. The first consists of clusters 1, 2, 5. It is more peripheral geographically and has higher lithic to ceramic ratios. The second more centrally located group, clusters 3 and 4, have lower lithic to ceramic ratios. However, the peripheral cluster 6 also has a lower lithic to ceramic ratio. It is possible to arrange these to emphasize their exponential character. Figure 8 plots these ratios expressed as percentages, as natural logrithims and as a base 10 logrithim.

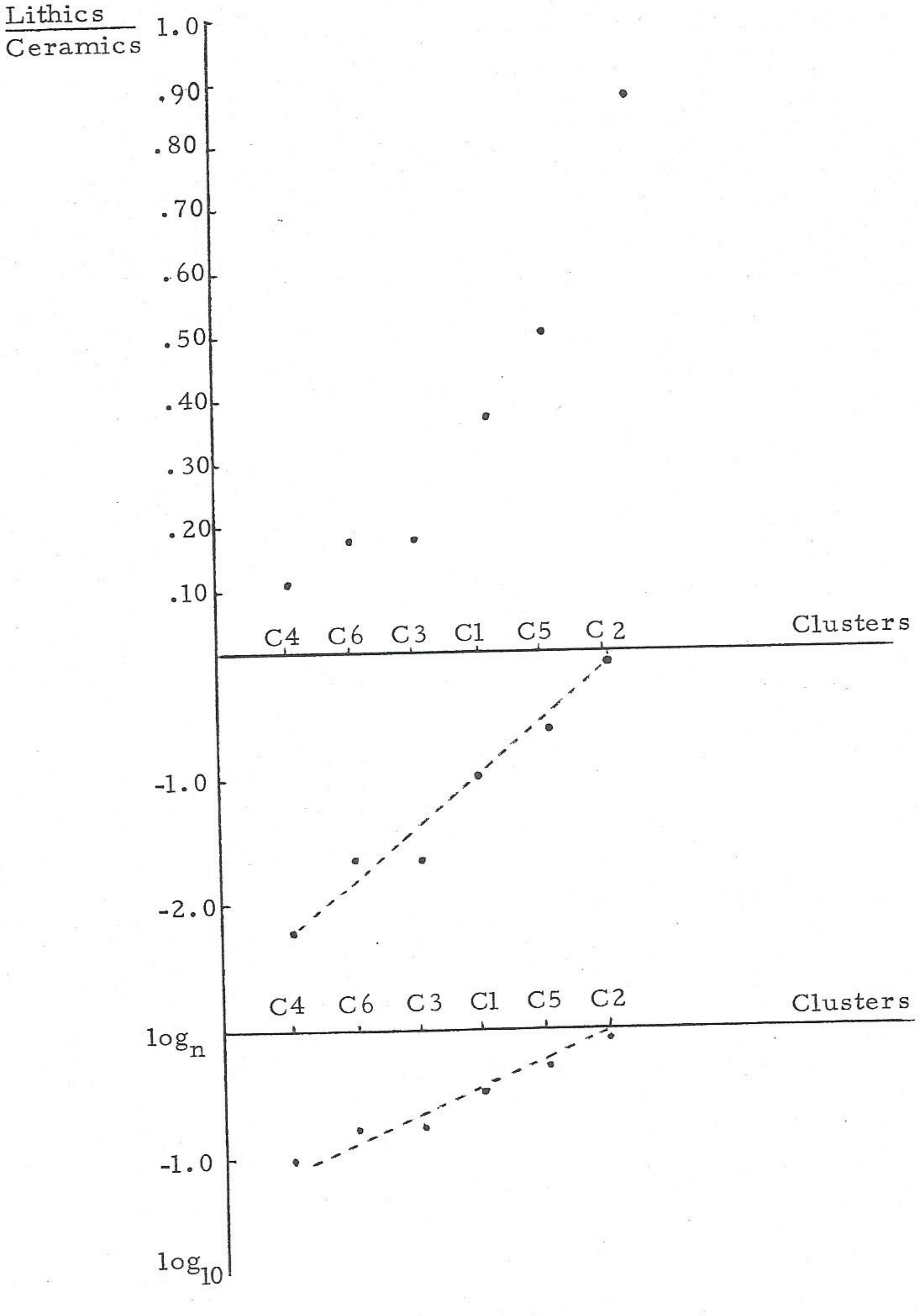
Why should these ratios be exponential? They do not correlate with the average size of sites per cluster, with the number of sites per cluster, nor with the chronology of the cluster (see chronology section). Therefore, a functional explanation is reasonable by excluding the other alternatives.

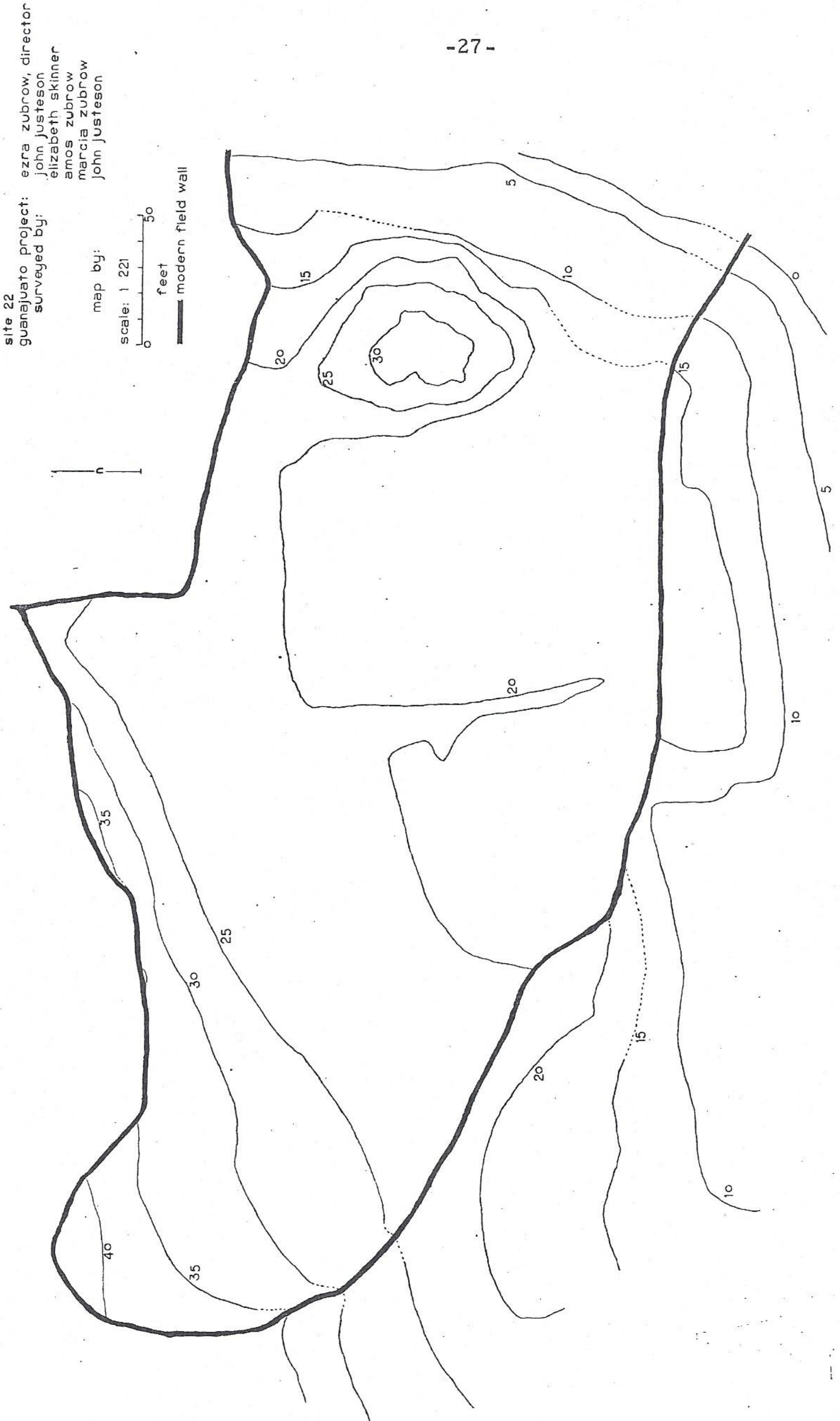
More information derived from this survey will become relevant when we consider the chronology of Cañada de Alfaro. A complete analysis of the survey data occurs in the Wilkens article included in this volume.

Detailed Surveying of Sites 22 and Site 43

In addition to the field mapping of each site as part of the systematic field survey, detailed contour maps were drawn of sites 22 and site 43 by transit. These sites were chosen on the basis of location, size, structural similarities, and excavation plans. Site 22 and site 43 are both located near the central intersections of the legs of the V (which makes up the distribution of the site). Site 22 is the largest structure in the zone; site 43 the eighth largest site (see Skinner "Labor and Size" in this volume). Both sites have similar structural characteristics. Each is a stepped mound which makes a platform on which a smaller pyramid, and a depressed plaza are located. Figure 9 is the contour map for site 22. The dimensions are dependent upon exactly where one measures the site for it is not exactly symmetrical. It is approximately 260' by 190'. From the base of the platform mound to the floor of the sunken plaza is 15', to the surface of the platform

Figure 8. Lithic to Cermaic Ratio for Geographical Site Clusters Expressed as %, $\log_n$, and $\log_{10}$




site 22
guanajuato project:
surveyed by:
ezra zubrow, director
john justeson
elizabeth skinner
amos zubrow
marcia zubrow
john justeson
map by:
scale: 1 221
0
50
feet
modern field wall
n
5
10
0
15
20
25
30
15
5
20
10
35
25
30
20
15
10
40
35

mound to the floor of the sunken plaza is 15', to the surface of the platform mound 20', and to the top of the pyramid is 30'. The sunken plaza is approximately 75' by 70'.

Douglas R. Mellis, an artist and scientific illustrator with considerable experience in Mesoamerican archaeological sties, spent several days in the field and many hours with topographic maps and field notes. He attempted to recreate the site as accurately as possible from a scientific and artistic perspective (Figure 10). He shows the site partially uncovered and reconstructed in its present environment. There is clear archaeological evidence for all the details (such as the proportions, numbers of steps in the platform mound, or the curved sides). The only exceptions are the staircases and the small man on the platform mound in which he has used artistic liscence.

Figure 11 is the topographic map of site 43. The site is more rectagular than site 22. It is approximately 240' by 280'. Although it covers a larger area, the vast majority of the site is not nearly as tall as site 22. From the base of platform mound (6038'), to the sunken plaza is 1.7', to the top of the platform mound is 4', and to the top of the pyramid is 13'.

From the survey, the south wall of the site showed two small step terraces on the platform mound (at 2' and 3'). The upper terrace corresponds to an actual step platform confirmed by excavation. The location of the excavation trench and test pits is shown.

Excavations:

In site 43, the excavations must be considered exploratory. Only a surface area of 288 square feet or 4/10 of one percent of the total site area were excavated. The excavation may be divided into two parts. Part one is the trench. It consists of six squares each 6' by 6'. Since the trench was placed on the edge of the mound, it was necessary to survey in a series of relative datum points. Each was of course tied into the site datum. Part two are the two test pits, square 9 and square 13, which are on the same east-west line as the trench. The trench and square 13 were excavated in a combination of artificial and natural levels. Each square within the trench and square 13 were excavated in 6" levels. Each 6" level was individually mapped by square and sorted for cultural materials. These materials were placed into separately labelled bags for each level of each square. These were then washed and analyzed in the laboratory separately. However, when there was an actual change in the geological stratigraphy, the artificial level ended, and a new level which corresponded to the natural stratigraphy was begun. Thus, we have a record of natural, cultural, and artificial stratigraphy.

Figure 10. Artist's reconstruction of Site No. 22.

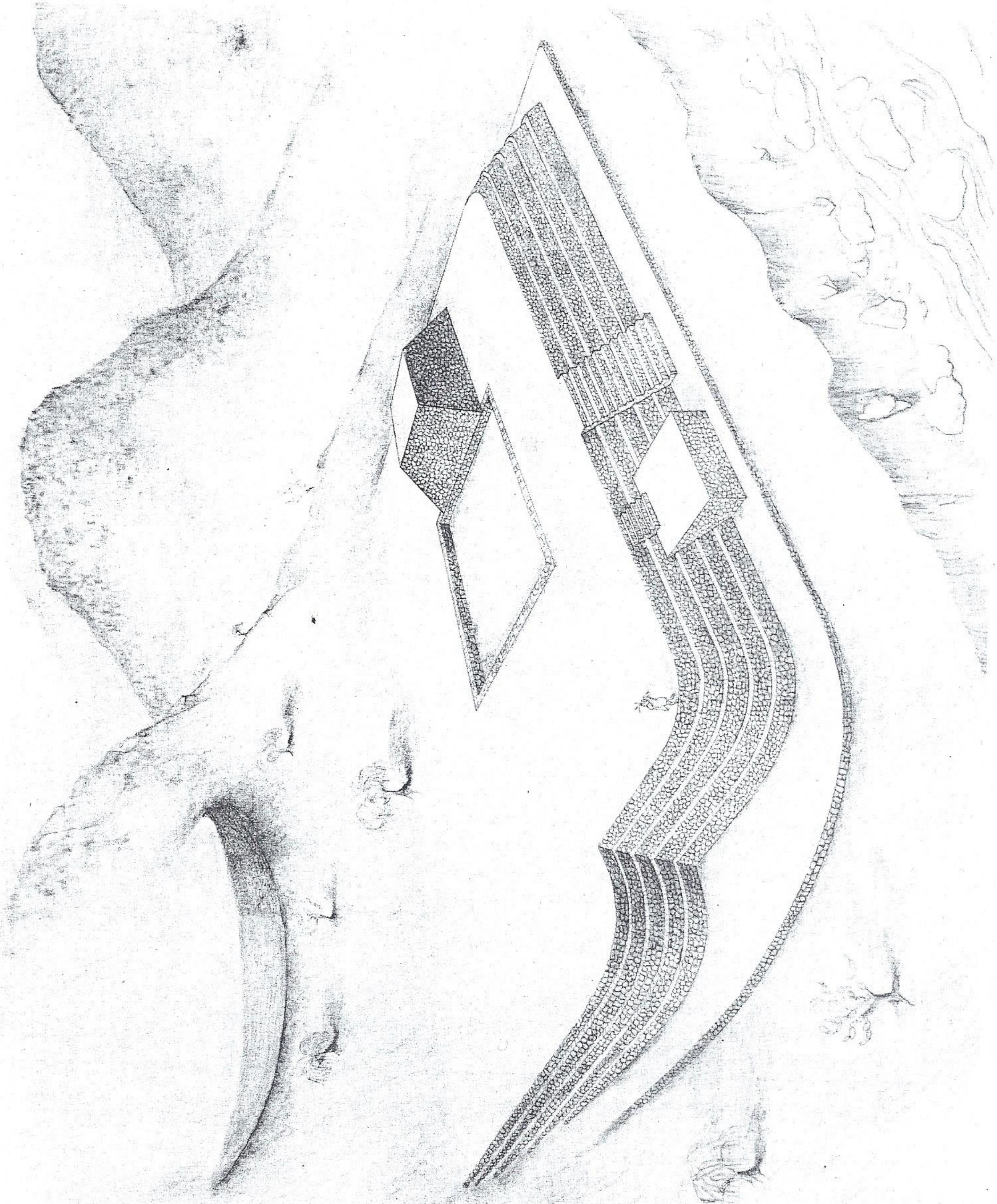


Figure 11. Topographic Map of Site 43, Cañada de Alfaro

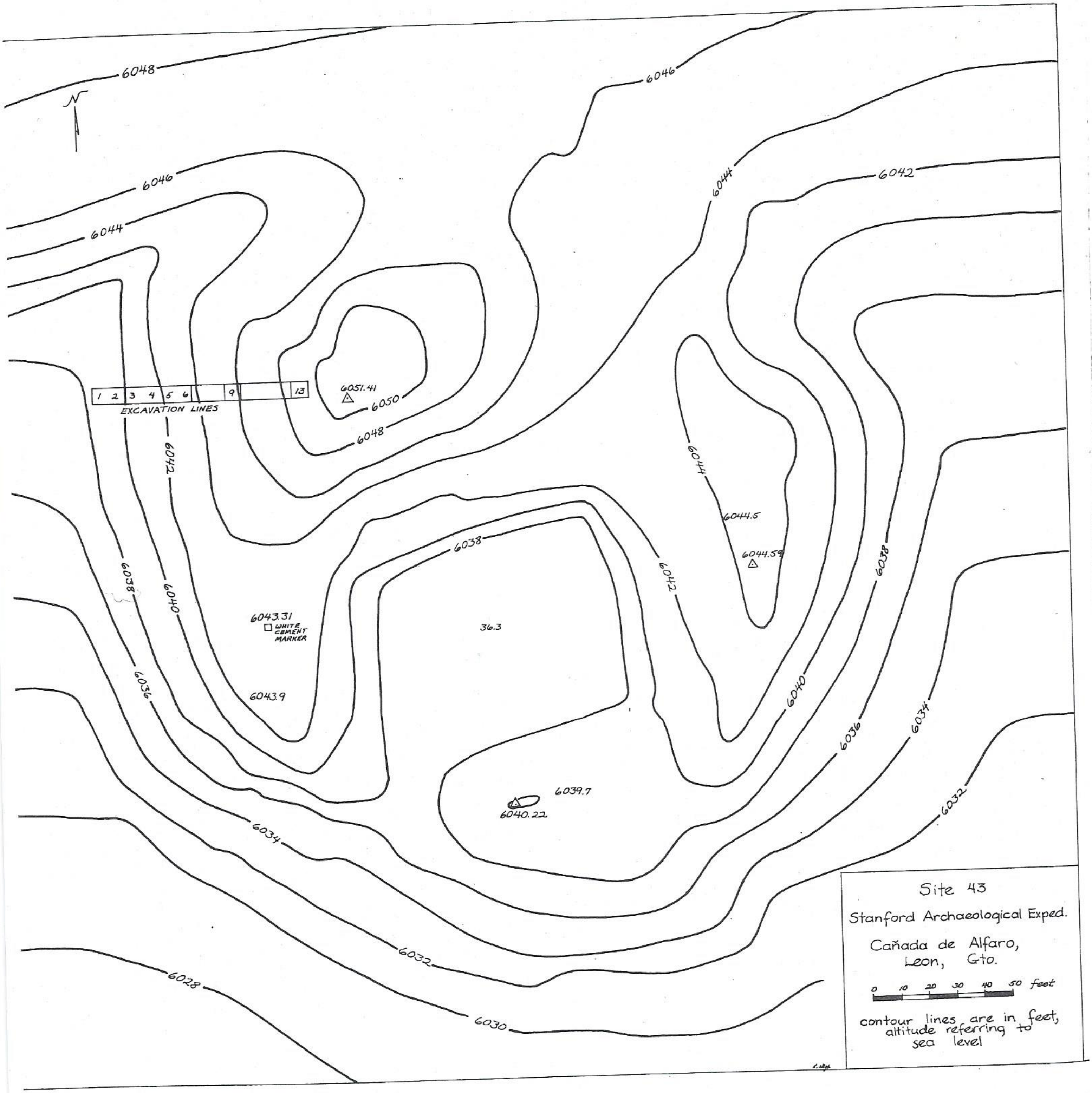


Table 3. Summary Data from Excavations in Site 43

Square No.	Relative datum	Approx. No. of art. levels excavated	Approx. No. of geological levels excavated	Absolute depth excavated	Number of ceramics	Number of lithics
I	-5.36	4	2	-24"	1111	166
II	-4.36	6	3	-36"	2594	363
III	-2.86	10	5	-60"	3789	278
IV	-1.86	13	12	-78"	2313	176
V	-1.36	14	11	-84"	3589	146
VI	- .86	15	17	-90"	3280	205
IX	1.64	x (26)*	12	-155"	1285	269
XIII	5.14	27	25	-159"	1643	169

After each square was finished being excavated, stratigraphic maps were drawn of all the walls to scale and mosaic photographs of the stratigraphy were made. C14 samples were also taken where possible.

The stratigraphy of site 43 is very complex. However, it is consistent to the extent that over 6' (from the north to south wall) of the excavation one is able to trace the same levels usually with small changes taking place. Figures 12 and 13 are simplified stratigraphies of the south wall of test pit 13 and 9. Figure 14 simplifies the stratigraphy of the north wall of squares 3, 4, 5, 6. The platform mounds artificiality is most clearly shown in Figure 10 by the deep stone level. This level consists of closely fitted stones the entire horizontal plane of the square, (6' by 6') by 3 1/2' deep. Figure 12 partially masks information about the step. What is not apparent from the cross section but which apparent from the horizontal sections of Square III is the large number of stones and their horizontal locations. As one moves down through the layers of the square, there is the following distribution of stone. Two of the top levels (18" - 30" below the surface) have a large number (35) of construction size stones (20"+ in diameter) in the western half of the square only. There are almost no stones in the eastern half. Between 30" - 42" below the surface, construction size stones cover the entire square. Other indications of the step are the faced stones and stones placed upon each other to make up the wall. The site, however, follows standard Mesoamerican construction techniques using a wide variety of material to fill the "rubble" interior of the mound.

---

*Square IX, the first test pit to be excavated, was not excavated by artificial levels.

Figure 12. Site 43 -- stratigraphy of test pit XIII (south wall).

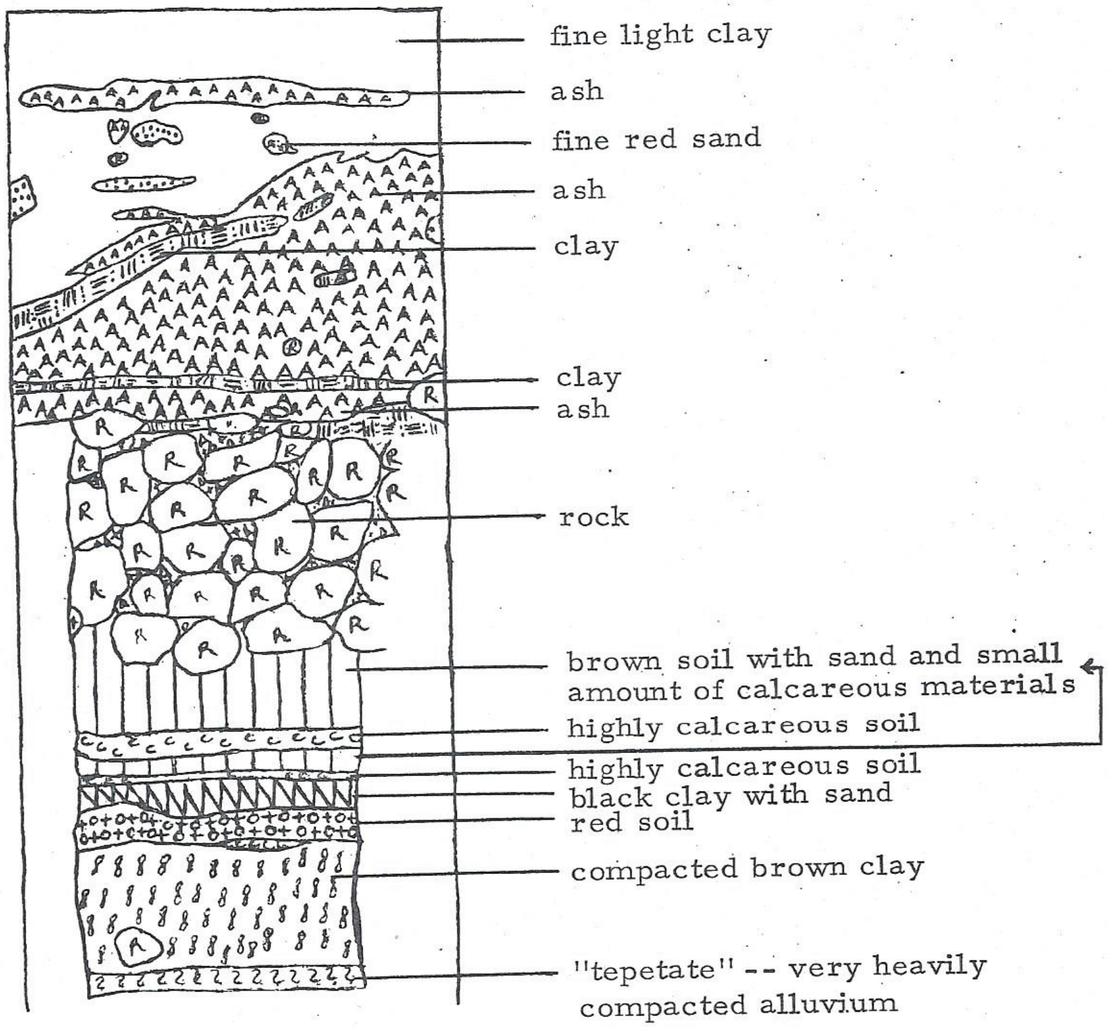


Figure 13. Site 43 -- stratigraphy test pit IX (south wall).

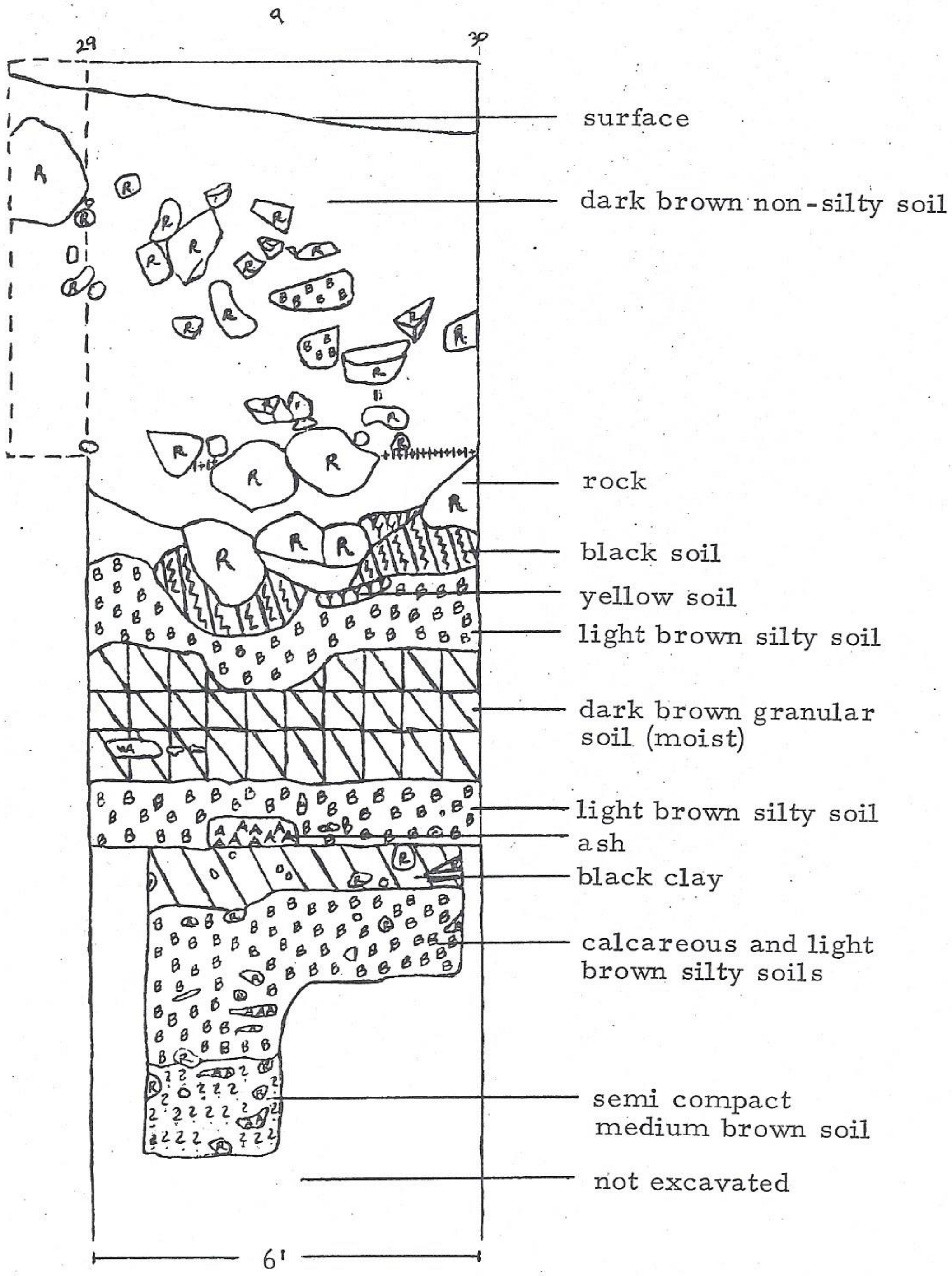
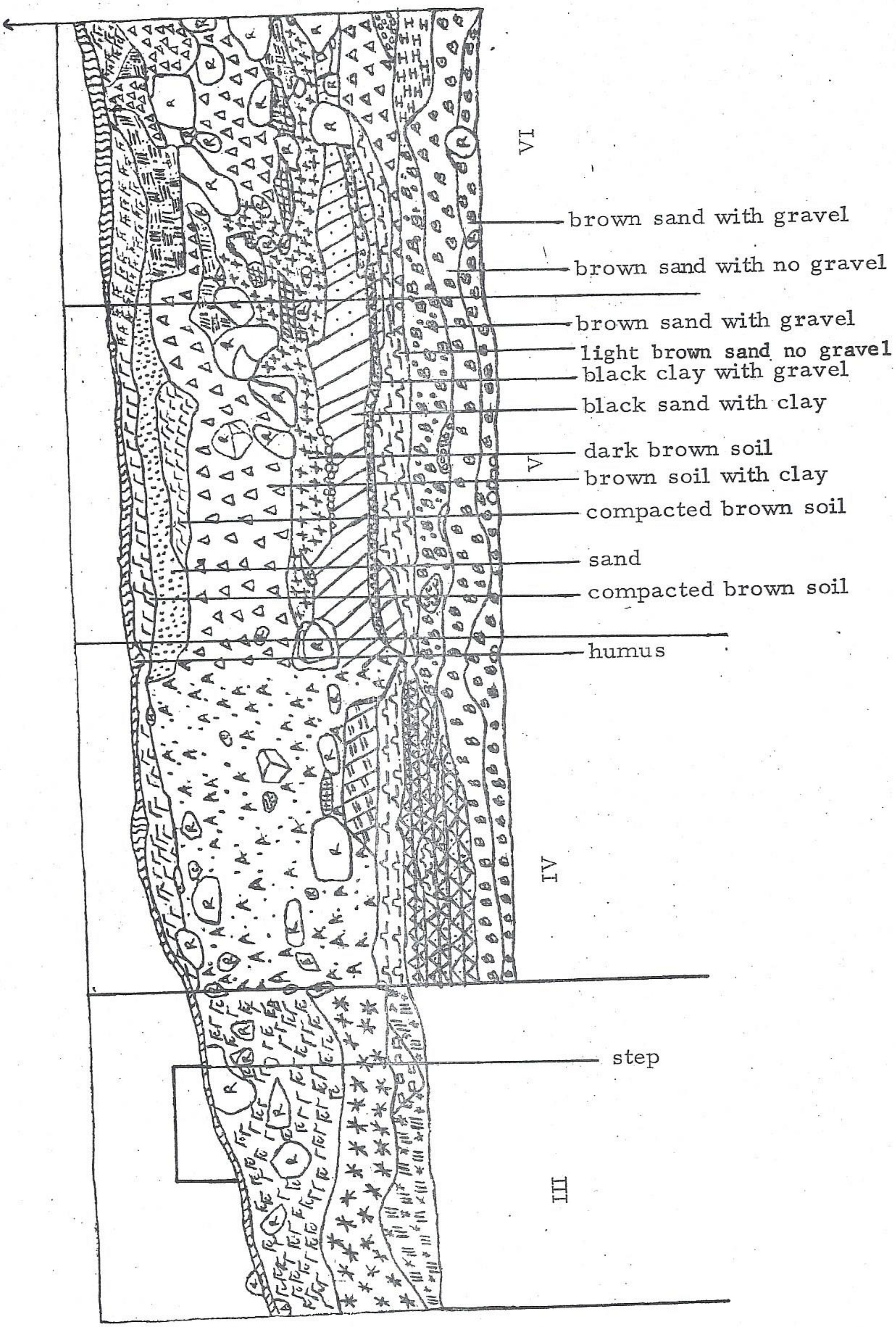

9
29
30
surface
dark brown non-silty soil
rock
black soil
yellow soil
light brown silty soil
dark brown granular soil (moist)
light brown silty soil
ash
black clay
calcareous and light brown silty soils
semi compact medium brown soil
not excavated
6'

Figure 14. Site 43 -- stratigraphy of squares III, IV, V, VI (north wall).



Other field analyses in Cañada de Alfaro

Two other types of field work were undertaken in the archaeological zone of Cañada de Alfaro. First, a series of stratigraphic samples were taken. In order to do this we used a porta-hydraulic drill (Model DR-2000) made by Soil Test, Inc. The utility of this model I originally tested in shell midden sites in Northern California in conjunction with excavations being conducted by John Fritz of the University of California at Santa Cruz. This drill allows one to excavate down to 25' or more below the surface and to take out cores varying between 1" - 3" in diameter. The exact diameter of the core is dependent upon the bit and coring sampler used. Complete sequences (vertically) of samples were taken on sites 10, 11, 22, 43, 57, 61. We thus have a stratigraphic picture of the sites to depths 44", 48", 82", 40", 57", and 94" respectively. Since the actual diameter of the holes is so small, the disturbance of cultural material was kept to a minimum (less than 1/1000 of 1%).

Artist and publication costs preclude actual publication of the sequences here. However, the drilling showed that the stratigraphy of site 43 includes all the structural materials that were used to construct the other five mounds. Their order in each sequence varied. In addition, the only other site with as complex a stratigraphy (i.e. number and variety of strata) is site 22.

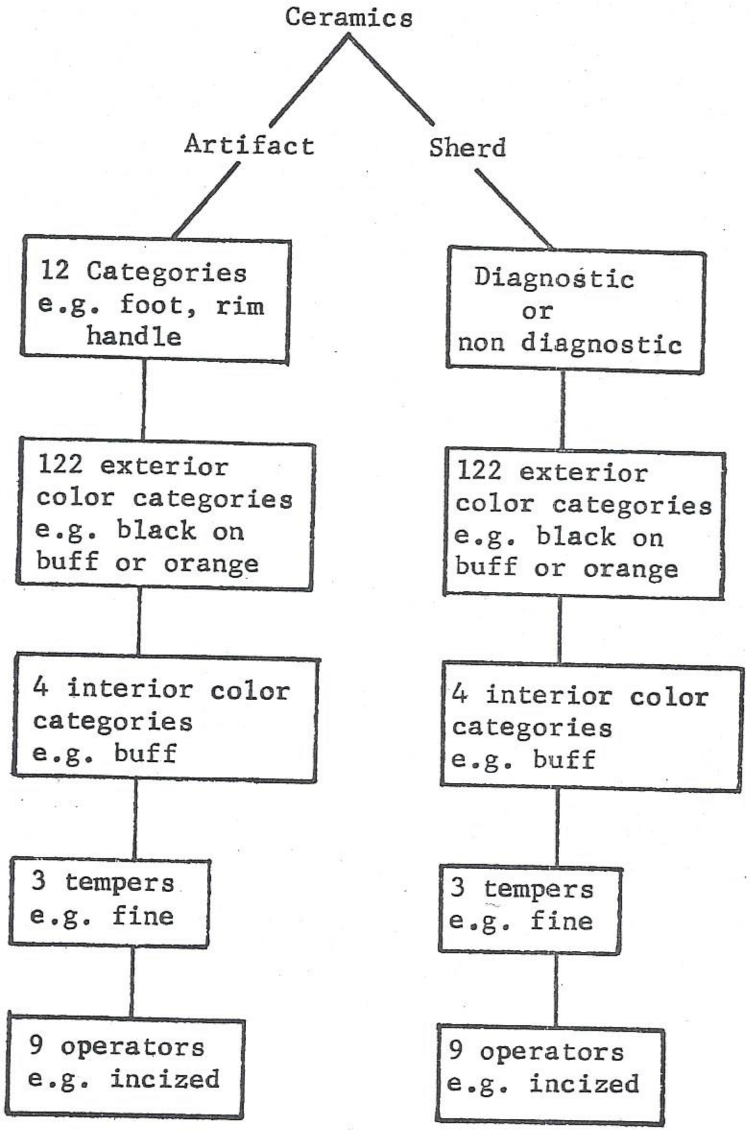
Second, a terra scout refraction seismograph (model R-150, Soil Test, Inc.) was used in conjunction with the drills to determine the stratigraphy. This machine is basically made up of three components, 1) the hammer, which strikes the ground creating a sound wave; 2) the geophone, which picks up the sound waves; 3) the oscilloscope, which records the sound wave on a cathode ray tube and measures the travel time of the wave between the hammer and the geophone. It is capable of determining the nature of sub-surface materials. A dense material such as granite will transmit sound waves much faster than loose material such as sand (e.g. 10,000 - 20,000 feet per second in comparison to 600 - 1200 feet per second). It is also capable of determining depth of subsurface materials since sound waves have the property of being refracted back to the surface when there is a high velocity material beneath a low velocity material. Multiple seismograph courses were run on sites 22, 43, 57, 61, 10, and 11 as well as the Rio Guanajuato sites.

With appropriate sampling, the internal shape of structures may also be obtained. A full report on this aspect of the analysis will be found later in this volume entitled "Archaeology and the Portable Refraction Seismograph."

Laboratory Analysis and Chronology

While the surface survey and excavation were taking place, laboratory analysis of the artifactual materials was begun. Every piece of ceramic or lithic material was classified and recorded by substance, number, and weight. The basic ceramic typology had 122 exterior color and decoration combinations (e.g. black on buff), 4 interior colors (e.g. buff), and tempers (e.g. fine). A short summary of the total depth of the ceramic typology is presented in Figure 15.

Figure 15. Summary of the Ceramic Typology


Ceramics
Artifact
Sherd
12 Categories e.g. foot, rim handle
Diagnostic or non diagnostic
122 exterior color categories e.g. black on buff or orange
122 exterior color categories e.g. black on buff or orange
4 interior color categories e.g. buff
4 interior color categories e.g. buff
3 tempers e.g. fine
3 tempers e.g. fine
9 operators e.g. incized
9 operators e.g. incized

There is at least one example of every criteria for distinction, but not for every possible combination of distinctions. For example, there is at least one example of each of the 122 exterior color combinations, at least one example of each of the 4 interior colors, and at least one example of each of the three tempers. But there are not examples of 1464 combinations of distinctions (i.e. 122 x 4 x 3), instead only some 310 or 21% actually show up in all the collections from the survey (i.e. 41,927 ceramics). A summary of the number of all ceramics from the 72 sites surveyed broken down by interior color and temper is below. It reveals a major hole in the combination of distinction actually occuring. In all the sites for all exterior colors, there are no ceramics with medium or course tempers and brown interior. In fact, there are virtually no ceramics with brown on the interior side of the vessel.

Table 4. Summary of Ceramics from 72 Surveyed Sites
Cañada de Alfaro

		Interior Color				
Exterior Color	Temper	Orange or Red	Buff	Brown	Black	Total
All	fine	6898	9752	2	2364	19016
	medium	7895	8800	0	3509	20204
	course	1125	924	0	658	2707
	Total	15918	19476	2	6531	41927

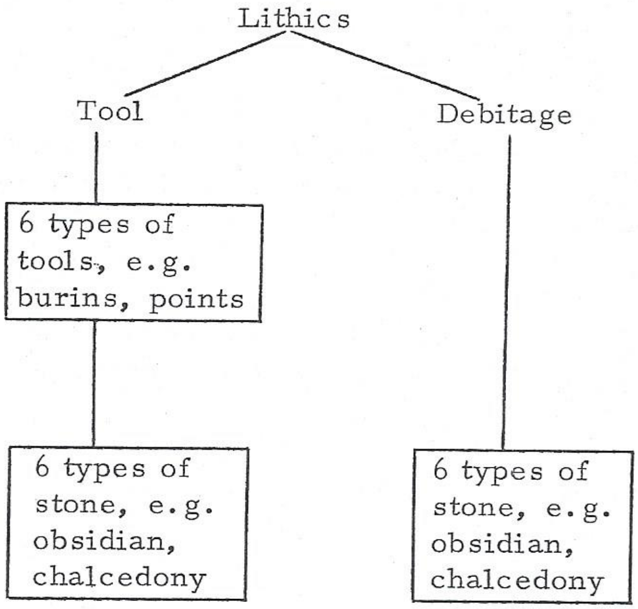
Potentially a piece of ceramics could fall into any one 184,464 categories (158,112 categories for artifacts and 26,352 categories for sherds).

Lithics were classified into tools and debitage and then appropriately classified into types of tools and by materials. A short summary of the total depth of the lithic typology is presented in Figure 16. The total number of lithics by material from the 72 surveyed sites is given below.

Table 5. Summary of Lithics from 72 Surveyed Sites
Cañada de Alfaro

Lithic Totals (by material)	
All materials	9088
Chert	5998
Chalcedony	2284
Jasper	406
Obsidian	398
Basalt Rock	2
Quartzite	0

Figure 16. Summary of the Lithic Typology


Lithics
Tool
Debitage
6 types of tools, e.g. burins, points
6 types of stone, e.g. obsidian, chalcedony
6 types of stone, e.g. obsidian, chalcedony

Quartzite appears only in the excavated material.

For either typology, the sites are analyzed by collection squares for the systematic stratified survey. For the excavation, each 6' by 6' square is classified by level. After the material was categorized, counted, and analyzed, the work continued at Stanford. (All the actual material remained in Guanajuato except for a 1% study collection which was returned after 6 months.)

Maps of the area were sent up to the Stanford Linear Accelerator to be run on the Monroe Optical Scanners. From these Optical Scanners were received on card output the X and Y coordinates of all the sites. The coded ceramic and lithic data was combined with the X and Y coordinates of the sites and processed. The in-putting of the data into the computer was done by a series of Wylbur terminals. Wylbur, a general intersystem communication network, allowed for rapid inputting of data, as well as rapid editing and correction. A series of cross tabulation matrices were run, by site, by type and by total. Since the result was 120,000 lines of data, it is impossible to reproduce it all here, as it takes up a stack of computer print-out 10 inches tall. This is conceived as the first step towards the utilization of a more sophisticated analyses such as seriation, hierarchical clustering analysis, discriminant analysis, etc. However, since meaningful generalizations may be made from these cross-tabulations, it will be hopefully useful to present some of them here. For example, out of the 72 surveyed sites,

1) 85% of the ceramics are non-distinguished buff, orange, orange-red, and dirty orange wares.

2) Only 4% of the ceramics are painted wares (e.g. Black on buff), but 57 different types occur.

3) Deborah Schlacter has shown for 46 of the 72 sites that a reasonably simple typology of the sites based upon the number of ceramics from each site's 10% sample and the density of ceramics is identical to a variety of simple typologies based upon ceramic types. (See Tables 6, 7). She has shown that it is possible to use at least 41 other ceramic criteria and come out with exactly the same categories of sites. No other grouping of the sites is capable of being created so many ways. In other words, this typology has the most redundancy through all the ceramics.

4) As one moves from early to late through the relative chronology of the sites, the diversity of types of ceramics decreases and then increases.

Table 6. Typology of 46 Sites Defined by Number of Ceramics in 10% Sample and Density of Ceramics per Volume Unit.

	11.00+	8.0-11.00	3.0 - 8.00	1.0 - 3.0	0.0 - 1.0 Density
2000 +	30 36	41	28	46	
1000 - 2000			8 27	22P 22 23	
0-300	60	7	50 57 57P 9 11 12	10 29 55 58 21	5 13 37 6 19 20 32 42
300 - 1000		63	4 1 16 59 69	15 48 3 53P 2 53 31 45	35 43

Table 7. Typology of 46 Sites Using One Set of Minimum Ceramic Criteria.

		Black +				Black −
		Red +		Red −		
		Brown −	Brown +	Brown +	Brown −	
Red +	Red/buff −	30 36	41	28	46	
	Red/buff +			8 27	22P 22 23	
Red −	Red/buff −	60	7	50 57 57P 9 11 12	10 29 55 58 21	5 13 37 6 19 20 32 42
	Red/buff +		63	4 1 16 59 69	15 48 3 53P 2 53 31 45	35 43

If one turns to the excavation, it appears that similar generalizations may be made:

1) As one moves from the early to the later stratigraphy, the diversity of types of ceramics decreases and then increases. For example, in one square the number of types decreases 87% and then increases by 267% as one moves upward through the stratigraphic column.

2) Most of the ceramics are the same undistinguished wares as in the survey. For example, buff, orange, orange-red, and dirty orange wares make up 74% while painted ceramics make up 2% of the ceramics in the square noted above.

Tita Braniff and her assistants were kind enough to explain and show to me examples of pottery classified according to her typology for Guanajuato. The following table includes some of the diagnostic pottery types by phase. The pluses indicate significant quantities found at Cañada de Alfaro.

Table 8. Diagnostic Ceramic Typology by Phase

Middle Preclassic	Corporo gray-brown	
	Negativo	+
	Hematite redware	
Upper Preclassic	Morales gray-brown	+
	Morales polychrome	+
	Morales red on buff	+
Early Classic		
Phase a) San Miguel	Blanco Levantado	+
	San Miguel red on buff	+
	San Miguel black	+
Phase b)	Rio Verde orange	
	Electra polychrome	

She also suggested that incized pottery on the interior of the vessels occurs primarily in the preclassic while incisions on the exterior occur primarily in the classic. Our analysis of a 1% sample (i.e. approximately 4,000 ceramics classified diagnostic or artificial) showed that for incized ceramics a ratio of 2:1 interior to exterior incisions. This suggests that the Cañada de Alfaro zone dates to the preclassic-classic boundary.

Turning to the lithics, several generalities appear appropriate. 1) Most of the lithics in the excavation occur in square 6. No tools occur until level -12 and -13 where they are found in considerable quantity. Below -13 the number of tools decrease. From level -1 down, the weight and quantity of each type of stone increases to -6 or -7, then it decreases to level -13. 2) The order of lithic quantities and quartzite in decreasing order which corresponds closely to what is found on all 72 sites surveyed.

Obsidian hydration was used as a relative dating method. A piece of obsidian being exposed to the atmosphere will form a ring around its exposed edges by hydration, the longer it has been exposed and the older its age. In order to be useful as an archaeological dating technique, it must be used on a piece of obsidian which was fractured prehistorically, a tool or debitage.

Forty-five samples were prepared -- one from each of 45 sites. Each sample showed prehistoric modification. Out of the 45 samples only 7 could be dated. Table 5 presents the obsidian hydration data.

Table 9. Relative Chronology by Obsidian Hydration

Time	Sites	Hydration measurement
late	27	1.0 m
↑	49	1.1 m
	18	1.2 m
	3	1.6 m
	43	1.7 m
	10	2.5 m
early	69	3.0 m

If one attempts to extend this chronology to other sites, an interesting phenomena occurs which reinforces the chronology. I examined all the sites which were grouped in the same ceramic grouping based on Table 6 as each site which had a obsidian hydration measurement. I calculated the average diversity of ceramic types for each ceramic grouping of sites with an obsidian hydration measurement and then organized these values by obsidian hydration date (see Table 10).

Table 10. Tentative Relative Chronology of Sites by Ceramic Groupings

Time	Sites by Obsidian Hydration Date	Grouping of Sites Ceramic Categories	Average Diversity of Ceramic Types
late	27	8, 27	18.0
↑	49		
	18		
	3	15, 3, 2, 31, 45	12.3
	43	43, 35	10.0
	10	10, 29, 55, 58, 21	11.2
early	69	4, 1, 16, 59	16

I then took all of the sites in each geographical cluster which had a site with an obsidian hydration date and calculated similarly the average number of ceramic types per cluster. I then organized these averages by obsidian hydration date. In this case also the diversity of ceramic types begins to decrease as one moves upwards through the chronology and then increases. This principle is exactly what also is operating as one moves through the strata in the excavation of site 43.

During the excavation of Site 43 in Cañada de Alfaro, several samples were taken from various areas and levels of the sample squares. These samples consisted of carbonized material. One sample, a small burned corn-cob, which was collected from Pit No. 13 was not analyzed by Carbon-14 dating. This sample was preserved by the Mexican Government as the only example of corn from this time period from the state of Guanajuato. Twelve other carbonized samples were taken to the U.S. for Carbon-14 dating analysis by Geochron Laboratories in Cambridge, Massachusetts. With the aid of Mr. Richard Pardi, the radiocarbon manager, I selected two samples of the twelve. These were the only samples which could be dated. I received a report on each sample. The essential data are as follows:

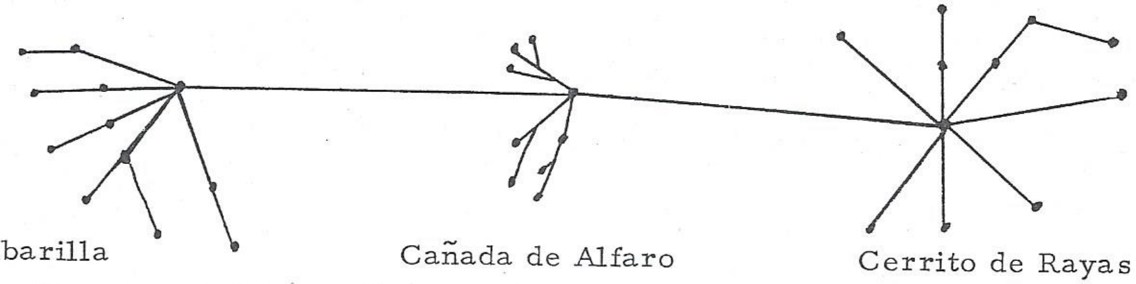
> Pre-treatment: Selected charcoal fragments were cleaned of foreign materials including rootlets, or other contaminating material that could be observed. They were then digested in hot dilute Hydrochloric Acid (HCl), and in hot dilute Sodium Hydroxide (NaOH) to remove chemical contaminants prior to combustion and analysis.
>
> Sample No. 1. From Site 43, Trench 1, Pit 13, Level 1.
>
> Description: Charcoal fragment, 1/2 to 1/4 inch.
>
> The age is 1710 ± 140 Carbon-14 years, B.P. (240 A.D.).
>
> Sample No. 2. From Site 43, Trench 1, Pit 13, Level 2.
>
> Description: Charcoal and bone marrow fragments between 1/16 and 1/8 inch.
>
> The age is 1500 ± 85 Carbon-14 years, B. P. (450 A.D.).

It should be noted that at the 1 δ level, these ages are identical and that no particular importance should be given to their relative ages. These dates are based on the Libby half life (5570) for C^{14}. The error stated is ± 1 δ as judged by the analytical data alone. The modern standard is 95% of the activity of N.B.S. Oxalic Acid. The age is referenced to the year A.D. 1950. These dates put site 43 at levels 1-2 very close to the Preclassic Classic border as did Tita Braniff's ceramic chronology.

In summary the laboratory analyses have not only shown a variety of generalizations about ceramics and lithics, but indicate that the Cañada de Alfaro zone dates to the Preclassic Classic boundary approximately A.D. 350. Furthermore, there is some evidence that not all the sites are contemporaneous based upon relative chronologies.

Other Zones

During the last decade the focus in archaeology has changed from emphasis on locating cultures in time and space to questions of cultural process, resulting in more explicit theoretical formulations and testing procedures. One area in which considerable interest has developed is regionalization and geographical patterning. Using archaeological and ethnographic evidence dealing with site distributions, we attempted to construct a communication net with sites being the nodes, branches being direct communication links, and weighing such attributes as cost, desirability, and capacity. Then we used a "shortest tree" solution in order to determine the median of the graph and predicted the existence of other zones at the medians. For example, Cañada de Alfaro lies near the median of the network between Ibarilla and the Cerrito de Rayas areas, as exemplified below:



We attempted to predict a median site between the Rio Guanajuato sites (see below) and Ibarilla clusters. We underestimated the amount of weighing, and it was not until considerably later that we located the L-S zone. This zone which I have labelled the L-S site is located 5.8 miles from Leon toward Silao along the Leon-Silao highway. (Measured from the Leon-Silao highway. (Measured from the Leon city limits sign). A track turns off the highway towards the east 2/10 of a mile from which the zone is easily visible. Someone has done considerable excavation previously. There is a 30 m by 3 m trench running North-South and two large 4 m by 4 m excavations. All of these are now in the process of gradually caving in. As of the time I am writing this I have not been able to find out who did the excavation and if it has ever been reported in print.

Two seismograph courses were laid out and ran (see Skinner). Otherwise, this zone was left undisturbed. I am particularly interested in this zone since it is analomous being over a kilometer away from any primary drainage, which is a secondary pattern. This pattern postulates the correlation of zones with primary drainage. This hypothetical pattern holds valid for Ibarilla (partially excavated by Emilio Bejarano) and Cañada de Alfaro. The Rio Guanajuato site was located on the edge of the first terrace of the Rio Guanajuato. It thus continues the pattern into the central Bajio. On this site a 10% surface collection was made for comparative purposes to the ceramics of Cañada de Alfaro and Ibarilla. In addition, three multiple seismograph courses were run (see Skinner).

It is appropriate to close this descriptive regional study on what other archaeological zones are known in Guanajuato. A wide variety of zones have been examined by expedition personnel, Emilio Bejarano as the regional archaeologist, as well as by other interested archaeologists and individuals. I have attempted to centralize and standardize information. Table 11 presents a summary compiled by Mary Lou Johnson-Schwartz, Benjamin Brown, Al Desmond, and Doug Mellis. It should be noted that this information comes from a wide variety of sources and people whose interest in the particular zones were variable. Therefore, this information is tentative and is clearly unequal in completeness, value, or veracity. It does not include the intensive work being undertaken by Shirley Gorenstein whose results will soon be available in a far more complete form. However, I present it for its potential value in stimulating more research in Guanajuato. Intensive research will surely modify this summary.

Table 11. Summary of Some Archaeological Zones in Guanajuato

Archaeological zone or site	Location	Known features or Structures	Ceramics	Lithics and Stone Works	Date	Remarks
1. Agua Espinosa	See Fig. 2	1 platform mound 1 pyramid, sherd scatters activity areas, plazas	some destroyed in Malo collection, Blanco Levantado, San Miguel Red/buff	cut stone	part of Tita Braniff ceramic sequence	at mountain-valley boundary
2. Three Crosses	See Fig. 2	linear alignment of potentially 4 aligned structures on terrace, 1 platform mound with pyramid	less 5 sq. in.	limestone evident		extreme erosion, one burial (based on teeth)
3. San Miguel Viejo	See Fig. 2	3 ceremonial mounds	less 5 sq. in. include figurines, painted and textured; surface collection Ben Brown	very sparse	part of Tita Braniff ceramic sequence San Miguel Red/buff (San Miguel Phase?)	
4. Flips Ranch	See Fig. 2	sherd scatters, ceremonial mound (?) wall	Red/buff, others	cut stone, manos, metates, 10/sq. m.		
5. Golf Course	See Fig. 2	rubble mound 1, stone alignments	absent	20/sq. m		information available at architects -- Schlee and Thiediecks office

Archaeological zone or site	Location	Known features or Structures	Ceramics	Lithics and Stone Works	Date	Remarks
6. Cabras	See Fig. 2	rubble mounds, ceremonial mounds, wall painting	less 5 sq. m	5-10/sq. m		rock painting, 1-5 K. SE surface collection by Ben Brown
7. Presa Allende	See Fig. 2	pyramid on platform, mound with sunken plaza, 2 sherd scatters	5/sq. m	1/sq. m		
8. Otto's Ranch	See Fig. 2	rubble mound, ceremonial mound, sherd scatters, stone scatters	10/sq. m	1/sq. m		
9. Cerro de Los Manos	See Fig. 2	walls, plaza, rubble mound, terraces				Ben Brown did surface collection
10. Cañada de Virgen	See Fig. 2	2 platform mounds with pyramids and sunken plazas, 1 rubble mound, 1 circular mound, double stone alignment	1/sq. m	worked stone 10/sq. m	Classic	
11 to 22	See Fig. 2					Presently under water -- SRH survey
23	See Fig. 2					located by air photo
24 to 25	See Fig. 2					verified location not precise

Archaeological zone or site	Location	Known features or Structures	Ceramics	Lithics and Stone Works	Date	Remarks
26 to 49	See Fig. 2					presently under water -- SRH survey
50	See Fig. 2					from SRH survey -- not verified
51. Barrio San Miguel-Leon	in Leon brickyard		no Chupicaro but bowls, lithic figures		Preclassic	reported in print by Tita Braniff
52. Ibarilla	near Leon See Fig. 1	circular structures, over rectangular structures as well as other structures	no blanco levantado		Classic	reported in print by Emilio Bejarano who excavated 9 burials
53. Chupicaro	near Acambaro	Summarized	elsewhere		Preclassic	Extensively studied and reported by Porter, Estrada and Pinachon.
54. Rancho Viejo a, b, c	near San Miguel (?)	terracing plazas, platform mound, pyramids				surface collection Ben Brown
55. Tarimoro		burial site on hill top, terracing platform structures	Chupicaro Blanco levantado (?)		Preclassic	
56. Salvatierra	near Salvatierra	ceremonial mound, activity area	Chupicaro collections in the Ahlondiga 5/sq. m	worked stone collections in the Ahlondiga 1/sq. m	Preclassic (?)	washed away in mud, excavated by amateur archaeologists

Archaeological zone or site	Location	Known features or Structures	Ceramics	Lithics and Stone Works	Date	Remarks
57. Tlaxcallia	near San Miguel	several mounds	surface collection			never excavated, collection in home of Paul Schmidt
58. Morales	near Morales		Morales grayincized		Preclassic-Classic	reported by Tita Braniff
59. Rincon de Parangueyo	volcanic area near Valle de Santiago	long tunnel into cave, rock paintings similar to that on Chupicaro vessels	present on floor of rock shelter	obsidian present on floor of rock shelter	Preclassic (?)	reported by Bejarano in print
60. Magdalena			Red/buff and blanco, levantado similar to Cañada de Alfaro		Classic	surveyed and excavated by William Godfrey
61. El Coporo	near Dolores Hidalgo and San Luiz de la Paz				Early Classic	excavated and reported by Tita Braniff
62. Tierra El Blanco			partially destroyed in Malo collection		Classic	reported by Tita Braniff
63. Carabino		ball court	plumbate		Classic	reported by Tita Braniff
64. San Damien	along Guanajuato San Miguel road	measured by Ben Brown				surface collection, Ben Brown

Archaeological zone or site	Location	Known features or Structures	Ceramics	Lithics and Stone Works	Date	Remarks
65. Xoconoxtle	along Guanajuato San Miguel road	measured by Ben Brown				surface collection, Ben Brown
66. San Martin	along Guanajuato San Miguel road	pyramids, platforms, plazas, measured by Ben Brown				surface collection, Ben Brown
67. San Bartolo	near village of San Bartolo	large ceremonial center, 2 pyramids on platform mounds with sunken plazas, other rubble mounds, sherd scatters, white plaster floor 5 cm thick on floor	10/sq. m	used as a quarry for building modern materials, 20 sq. m obsidian blades	Classic (?)	
68. Ojos Zurco		large structures courtyards, caves			Classic (?)	never excavated similar to Aqua Espinosa
69. Charca Blanca		one mound	Red/buff			excavator unknown
70. Rio Guanajuato	on Rio Guanajuato first terrace where crosses highway Silao and Irapuato	2 mounds (see discussions in this monograph)				analysis not completed but begun by Guanajuato Prehistoric Regionalization Project

AGRICULTURAL PATTERNING

Ezra B. W. Zubrow

Agriculture as an Invasion

It is possible to look at agriculture as the artificial introduction, an invasion, of a series of plants into an already developed natural ecological community. Considerable work has been done by various scholars dealing with invasions. Ecologists include such well-known names as Elton, Watt, Pielou and MacArthur. More closely, however, to the subject at hand, Binford and Flannery have used the concepts of artificial radiation, diversity, and the stability of environment for analyses of the origins of agriculture. Geertz and Rappaport have used these concepts to explore the relationship between cultural and environmental variables. By culture, I mean man's extra-somatic adaptation to his environment. By environment, I mean that part of man's natural world which he does not manipulate. From this perspective the patterning of agriculture is a cultural mechanism for adapting to and controlling diversity, stability and productivity.

Definitions

In order to understand this theoretical stance a series of definitions will be needed. By invasion we mean the process by which an organism spreads from one, "the original," community to a new community and successfully adapts to its new habitat. Invasions must be seen in the context of barriers and refuges. A barrier is any physical or ecological factor which inhibits dispersal or invasion and thus effectively acts as a mechanism of isolation. A refuge is an isolated habitat often protected by barriers which has preserved ecological (such as lack of predators) and/or environmental conditions (such as climate) which were more common in the past. Agriculture is the artificial introduction of plants into a habitat of plants for human use, i.e., an artificially stimulated invasion. By agricultural patterning is meant the repetitive contiguous succession of agricultural fields.[1]

By food chain we mean the transfer of energy through the consumption of one type of organism by another. For example, herbivores consume plants and carnivores herbivores. Although food chains vary from one to five trophic levels, there are rarely more than five because the amount of available energy for additional organisms is greatly reduced by heat loss at each successive consumption. However, exceptions do occur since the efficiency of energy transferred varies enough for this to become possible. Thus, food chains may vary in complexity and in the number of different types of organisms which are dependent upon each other.

---

[1] For example, a transect showing the following sequence of fields, [corn, cotton, beans, corn, cotton, beans, cotton, cotton, sorghum, squash, corn] contains two patterns. One is [corn, cotton, beans], the other is [cotton]. Each is repeated twice.

In order to measure the complex series of related food chains which form an ecological community, the concepts of stability and diversity are necessary. By stability is meant the persistence through space and time of an ecological system. Diversity is a non-temporal measure of the distribution of the biomass. Most measures relate the number of species to the size of the population of each species in various ways. Diversity is related in two ways to community stability. First, by increasing the diversity of species of prey one adds alternate food sources for the predators. This enhances stability because there are more chains or routes by which the predators may be supported if there is a sudden decrease in one species of prey. Second, diversity among predatory species feeding on the prey will result in greater stability and control of the prey population. Changes in the size of one predatory population will be compensated by the size of the changes in the other predatory species, thus minimizing the change in the population of the prey. Later, it will be our contention that although development of agriculture is an invasion which takes place in communities with low diversity and thus short food chains, the patterning of developed agriculture allows man to partially control the diversity of the community, the size of the food chain, and most importantly the productivity. The rationale for this viewpoint is explained in the following sections.

Characteristics of the Invaders and the Invaded Environments

The invaders, whether they are supposedly beneficial plants to man, such as agricultural strains, or harmful pests such as crabgrass, have certain common biological characteristics. First, they have the ability to adapt to a variety of new environments and are thus reasonably generalized. Second, in comparison to most species they have a relatively high reproduction rate. Third, they tend to have competitive advantages which allow them to obtain exclusive occupation of their niches. Fourth, they tend to be relatively more transient than most species.

Man's cultivation of plants is an attempt to create a monoculture, an artificially simplified community, by weeding out competitors and thus increasing production. This reduces the diversity index of the community. This initial competitor reduction is reinforced two ways. First, man's conscious attempts at herbivore control even at such a simple level as keeping animals out of the fields, reduces the range available to herbivores and decreases the number of species actually subsisting off the fields. Second, this change in herbivores is reflected in unintentional changes in the carnivore distribution

(Elton 1958). The artificial instability of these communities are apparent to anyone who has observed the relatively rapid changes which take place in agricultural localities when fields are abandoned. The history of agricultural breeding and selection has been a continual attempt to increase the reproduction rate and thus, the yield. This selection process has often made species more specialized but there have also been periods of selection for more generalized species thus increasing the yield by allowing more land to be put under cultivation.

What type of communities are invaders most likely to succeed and have a population explosion? The answer is natural communities with low diversity indices (i.e., species poor communities). There are both fewer competitors and predators.[2] In addition, there are two requirements that must be met by the new environment. Not only must the environment be sufficiently benevolent as to allow the invader to survive, but it must also be possible for the invader to reproduce.

Principles for Invaders

It is now possible to state a series of principles involved in the successful invasion of foreign agricultural plants into a new community. They are:

1. The stability of a community is directly related to the diversity of species to populations, the number of trophic links (i.e., depth of food chain), the productivity of the species, and the predictability of the environment. $S \propto [DI, TL, P, Pr]$.

---

[2] There are three types of species poor situations: new communities, where the number of species are increasing; severe environments, where a small change causes large abiotic results; and unpredictable environments, where there is large spatial and temporal variation of the properties of the environments around their mean. These categories are not mutually exclusive. L. Slobodkin and H. L. Sanders (1968) have shown that species in low predictability areas will be subject to more probable extinction than species in high predictability areas. Also, invasions from high predictability areas to low predictability areas are more probable to succeed than vice versa. Thus, we would expect new agricultural invaders to be most successful if they came from high predictability areas and were being introduced into new species poor communities at an early stage.

It will thus behoove us to briefly look at the changing characteristics of new environments in more detail. The early stages of a new environment are usually characterized by a dominant species which is a general list and "broad niched." Later, as the community becomes more mature, it is replaced by a set of more specialized species which are "smaller niched."

2. The probability of a successful invasion is inversely related to the stability, diversity, productivity, predictability, and barriers of the recipient community, $I \propto \left[\frac{1}{S}, \frac{1}{DI}, \frac{1}{TL}, \frac{1}{P}, \frac{1}{Pr}, \frac{1}{B}\right]$, and directly related to the stability, etc., of the donor community.

3. The probability of a population explosion of the invading population is inversely related to the diversity of the recipient community and the number of refuges within the recipient community which allows competitors to survive $P \propto \left[\frac{1}{DI}, \frac{1}{R}\right]$.

Catch 22 and/or Hedging Man's Bets

Previously we stated that agriculture is an artificially simplified community, ideally a monoculture with increased production because of minimal competition. However, this viewpoint is based on a simplified view of reality. First, even if there were a single ideal agricultural crop which would fulfill all of man's nutritional needs (i.e., the ideal monoculture), man's penchant for novelty would probably lead to an increased number of crops with differing requirements. Reality, however, shows that even a *large number* of different crops are insufficient to meet man's nutritional needs. In short, diverse nutritional requirements cause diverse agricultural crops. Second, for man it is not enough that there is a successful artificial invasion. The *size* of the payoff in the crops must be sufficiently large to offset the varied economic costs, such as labor invested into producing the crop, etc. Third, for agriculture to be successful it cannot be a haphazard proposition. Over long time spans and in a variety of environments there must be a *high probability of success* in terms of large payoffs for a variety of crops.

A farmer is faced by Catch 22. If he attempts to increase production by decreasing competition, the size of the payoff goes up, but the long term probability of success goes down. His overall nutrition may also go down because he is planting fewer types of crops (less diversity). If he attempts to increase the probability of success (as well as his interest in his diet) his payoff goes down. Conservative peasant communities are well known for opting for small, traditional plots, planted in a diverse set of crops. Agricorporations with their larger savings base opt for land consolidation and monoculture.

One may view these land use strategies as two ends of a continuum. Monoculture is a uniform distribution of one crop. Multiculture may be

UNIVERSIDAD DE GUANAJUATO
BIBLIOTECA DE LA ESCUELA DE FILOSOFIA Y LETRAS

defined as the most non-uniform (random) distribution of a large number of crops. Patterned agriculture is, of course, the middle part of the continuum — an intermediate number of crops partially patterned (see Figures la. and lb. below). I use the terms mono and multiculture rather than simply mono and multicrops to distinguish that these strategies are the results of both the number of crops and the patterning of the land use.

Figure la.
Agricultural Land Use Strategies
The Terms: and the Axes

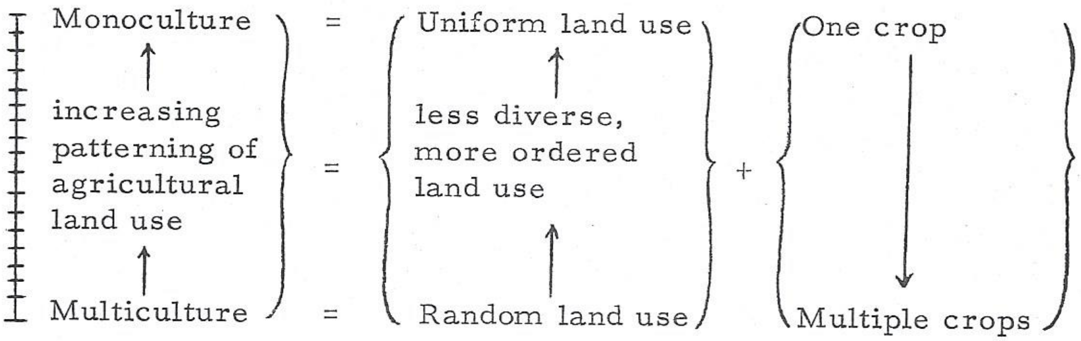
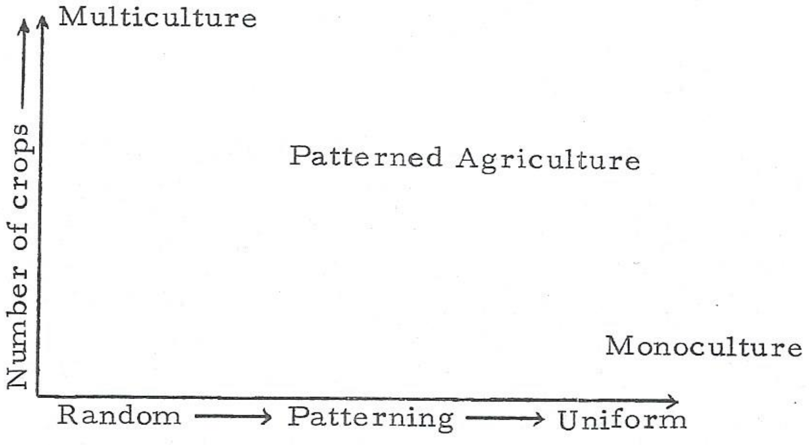

Monoculture
increasing patterning of agricultural land use
Multiculture
=
Uniform land use
less diverse, more ordered land use
Random land use
+
One crop
Multiple crops

Figure lb.
Agricultural Land Use Strategies



Recipient Communities and Land Use Patterning: Hypotheses

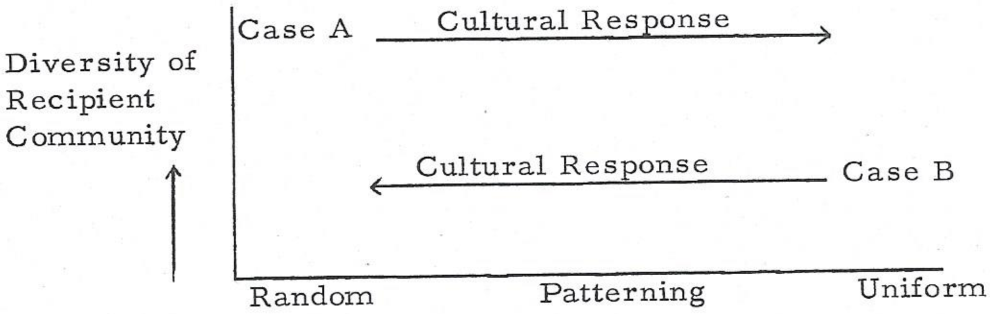
Let us examine what kind of land use patterning one would expect under differing types of natural communities. As previously noted, diverse communities are poor candidates for population explosions of invaders, i.e., large production of agricultural plants (Principle 3).

Thus, in a diverse community the cultural problem is to increase production. One would thus expect a large amount of land use patterning which would culturally shift the system closer to monoculture and the desired increased production (Figure 2, Case A). In addition, since the recipient community is diverse, the total system is reasonably stable and can tolerate greater variability in the amount of land use patterning.

Under conditions of a non-diverse recipient community, the cultural problem is to increase stability of the recipient community. (One needs only note Principle 1. Stability is directly related to diversity.) Since the non-diverse recipient community is the ideal candidate for the population explosion of agricultural plants, the potential for high productivity may already be assumed. The cultural solution is to decrease the amount of patterned land use (Figure 2, Case B). In addition, since the recipient community is not too stable, it cannot tolerate a large degree of variability in the amount of land use patterning.

Figure 2.

Cultural Solusions to Diversity Problems



A Test Case

The minimum requirements for a test case are two communities preferably in two environmental zones and the measured amount of patterned land for agriculture across these zones and communities. Although the two zones would guarantee differences in diversity, the transition between the zones theoretically would be more diverse than either of the homogeneous zones. During the summers of 1972 and 1973 Stanford University, the University of Guanajuato, the Mexican National Institute of Anthropology and History have been conducting an archaeological research project in Canada Alfaro, Guanajuato, Mexico.[3]

---

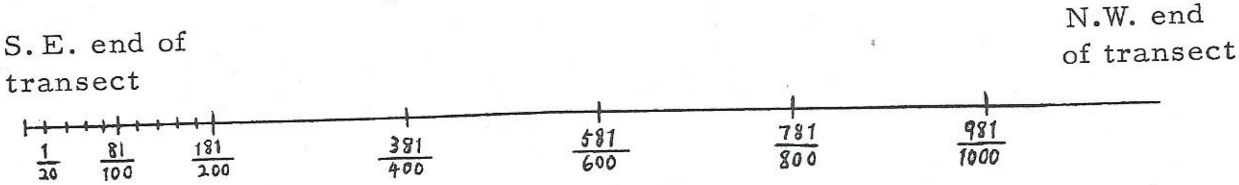
[3] This work financed by the Stanford University Research Development Fund, Latin American Studies, and a variety of administrative agencies of Stanford University.

As an adjunct to the archaeological data from 73 preclassic-classic sites, environmental and agricultural patterning data was collected on the ground along the entire length of a 180 mile transect. This transect began about 21 miles north of Mexico City and continued northwest to the city of Leon.

Definition of Environmental Zones and Transitions:

A cursory examination of the general environment showed that the transect crossed two zones. One zone, closer to Mexico City, was a semi-mountainous area with small dessicated valleys, the other consists of large alluvial valleys ringed by mountains. The boundary between the zones is not a clear cut knife's edge, but a transition whose location is partially dependent on what environmental parameters one is measuring. Table 1 presents the location on the transect of the environmental transition points for a variety of environmental parameters. These are graphed spatially on the transect in Figure 3b. The zones and the transition are identified and located also in Figure 3b. The transition is determined by the relatively larger number of transition points in the relatively smaller area. (Figure 3a. is included to orient the reader to the relationship between the graph's field-number axis and the actual transect.)

Figure 3a.
Explanation of Sequential Field Numbers



(Each unit on the axis equals 20 fields. Each 20-field group is located geographically (i.e. sequentially on the transect).

Figure 3b.
Location of Ecological Transition Points on Transect

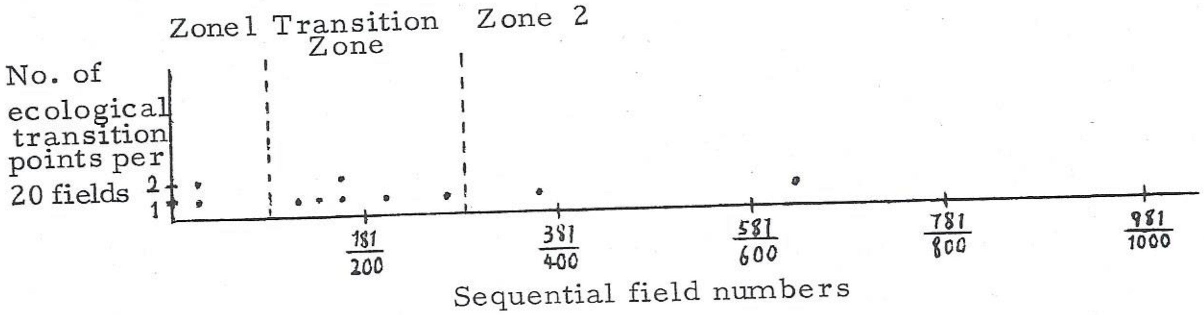


Table 1

Location of Environmental Transition Points on Land Use Transect

Transition	Transition From	To	Mile No.	Land Use Field No.
1. Koppens Climate Classification	Cwb	Cwa	47	213
2. Mean annual precipitation	750 mm	600 mm	41	150
3. Relative variability of mean annual precipitation	20%	25%	4	16
4. Relative variability of annual precipitation anomalies	-5.0	-2.5	39	139
5. Surface geology	quatenary alluvium	quatenary limestone	3	12
	quatenary limestone	tertiary extrusive	35	111
	tertiary extrusive	quatenary limestone	54	274
	quatenary limestone	tertiary extrusive	109	648
6. Natural vegetation classification	mesquite-grasslands	pine-oak	41	150
	pine-oak	mesquite-grasslands	66	360

Measuring Agricultural Land Use:

Along the transect land use was measured sequentially. Every time there was a change in crop or land use new measurements were made in the field. Thus, a segment of the transect might read:

Field No. 457	Corn	100 m
458	Fallow	25 m
459	Corn	50 m
460	Non-agricultural Land	200 m
461	Fallow	25 m
462	Corn	25 m

The data will be classified here into four categories: Corn (C), Fallow (F), Non-agricultural (NA), and other crops (OC).

It is possible to show part of the actual land use pattern along part of the transect in a clear visual manner. There exists a very powerful technique for analyzing remote sensing data called pseudo-color density slicing. It makes it possible to distinguish slight gradations in photographs. Figure 4 shows a black and white aerial photograph of the northwest end of the transect. Figure 5 shows the same photograph using a delay to emphasize the land use patterning. The pseudo-color density slicing technique makes it possible to demarcate different types of land use through the electronic mapping of different colors to show the differences in fields; e.g. fallow, non-agricultural, plowed, newly planted and planted agricultural fields. The figures above and the multiple color photographs were made possible by the exceptionally fine equipment and courteous help given me by International Imaging Systems of Mountain View, California. Cost, however, precludes their publication here.

Figure 4. Aerial photograph of the archaeological zone of Cañada de Alfaro and surrounding area including the northwest end of the transect.

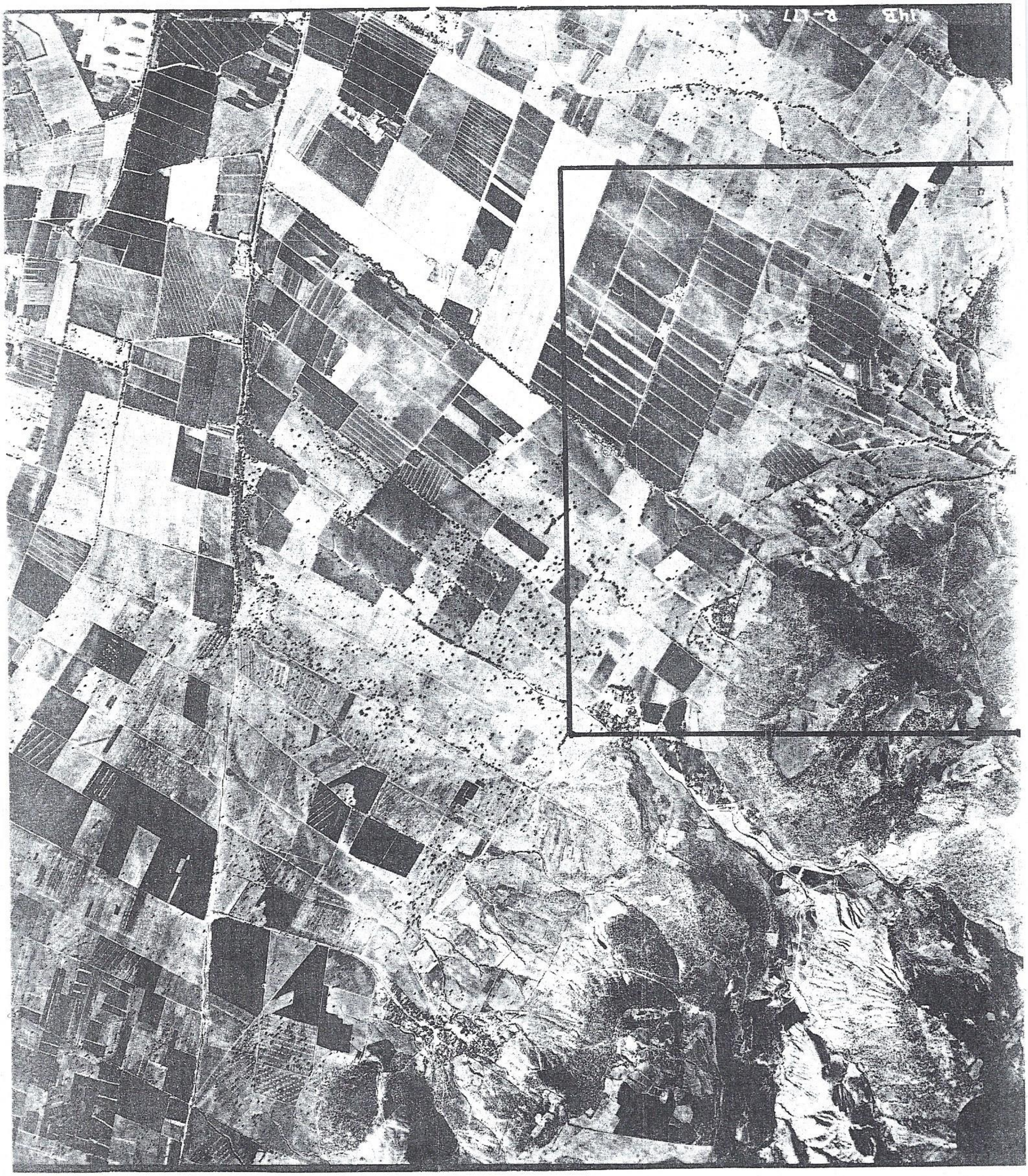
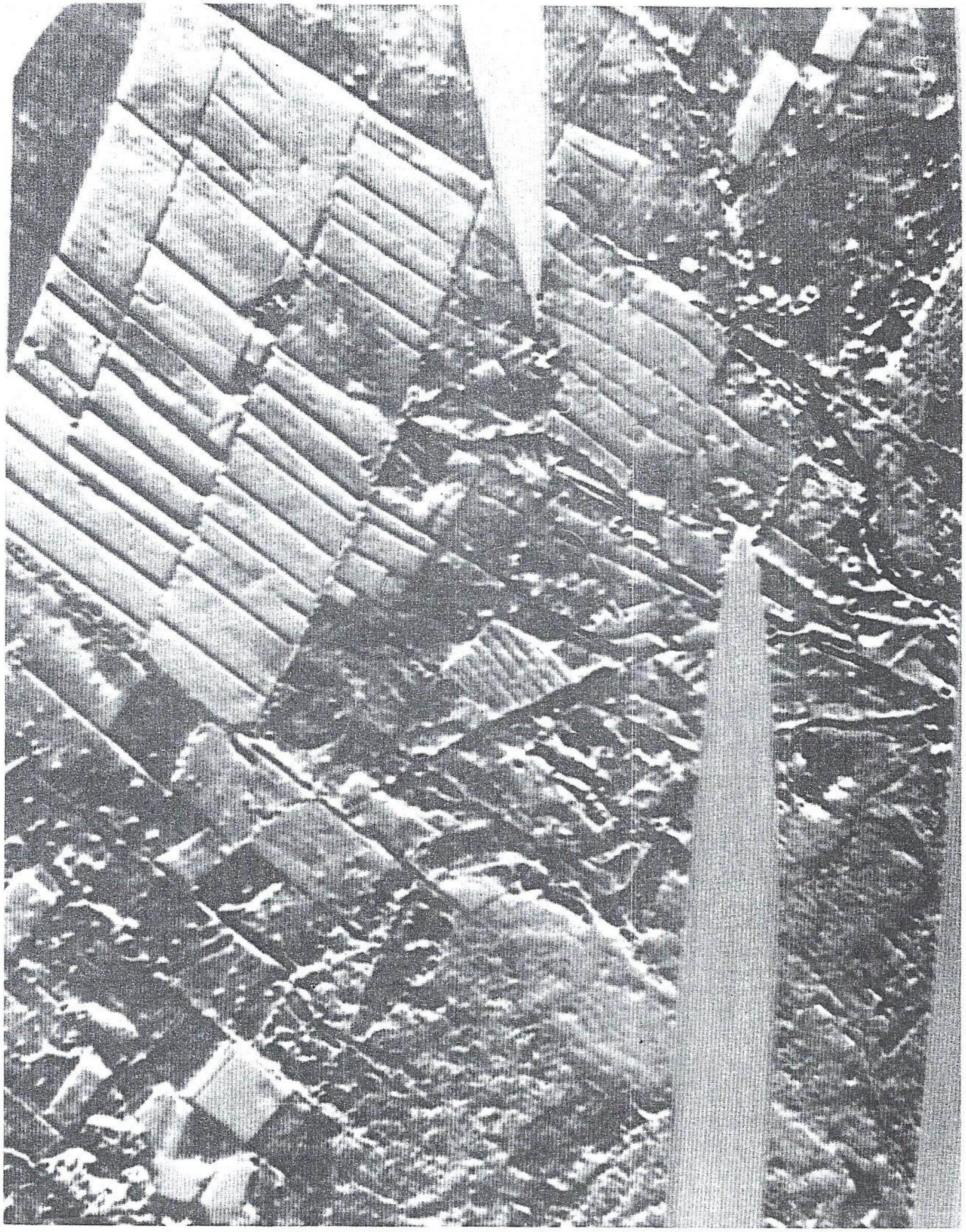


Figure 5. The area of the inset in Figure 4 using a 250 nanosecond delay to emphasize field patterns (negative).



The land use data was searched for patterns. All possible repetitive patterns up to an eight character segment were compared to the transect data (see Figure 6 below).

Figure 6
Comparison of Repetitive Pattern to Transect Data

Pattern	——→	C, C, F, C, C, F,	——→
Transect Data	... OC, NA,	C, C, F, C, C, F,	OC, F, C, NA, ...
Field Number	570 571	572 573 574 575 576 577	578 579 580 581

positive comparison of a
repetitive 3 character
pattern, CCF.

The number of actual repetitive patterns per 20 fields has been plotted sequentially in Figure 7a. In other words, the number of repetitive patterns in the first 20 fields of the transect, sequential field numbers 1 - 20, were counted and plotted as a point; then, the number of patterns for fields 21 - 40, etc. Thus, as one moves along the graph from field numbers 1 - 20 to field numbers 981 - 1000, one is moving sequentially from one end of the transect to the other recording the amount of patterning. A three point running average of the amount of patterning has also been plotted sequentially in Figure 7b.

Figure 7 a.
The Amount of Land Use Patterning per 20 Fields

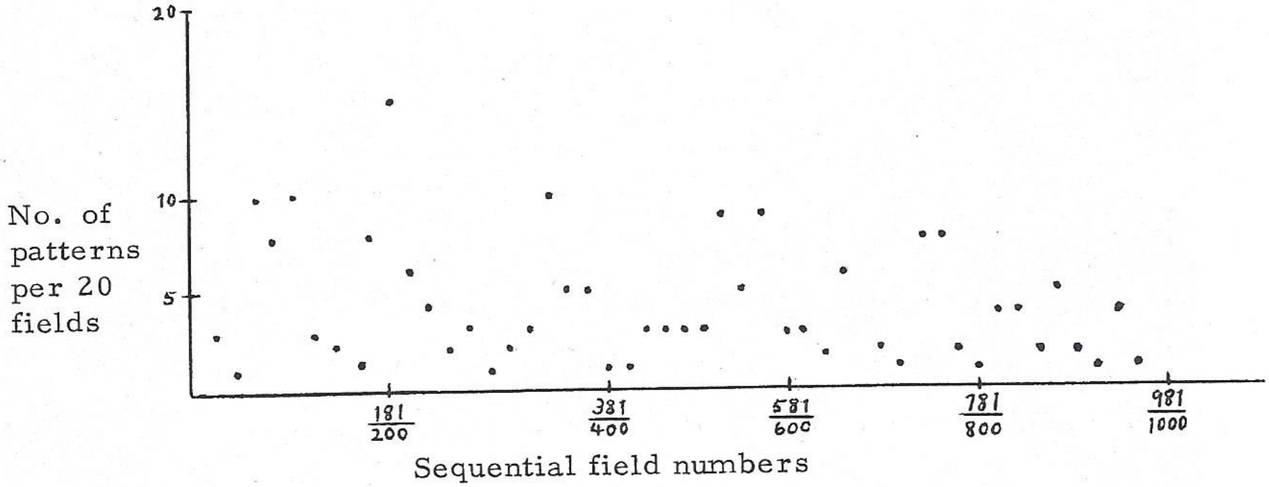
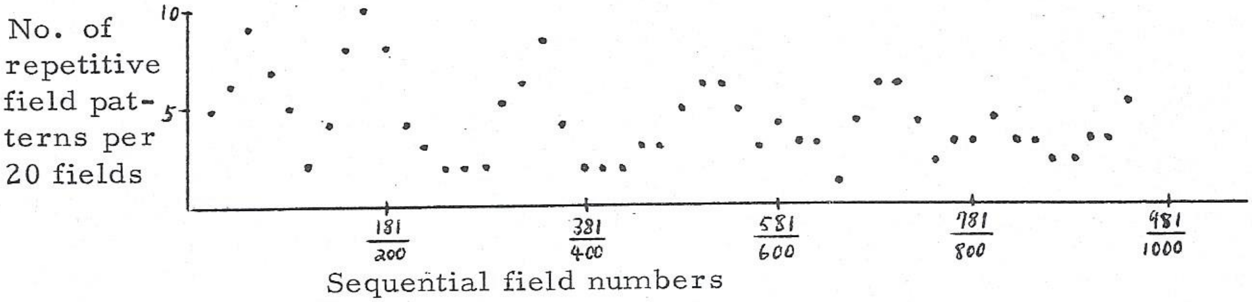


Figure 7b.
The Amount of Land Use Patterning per 20 Fields
(3 point running average)



Results:

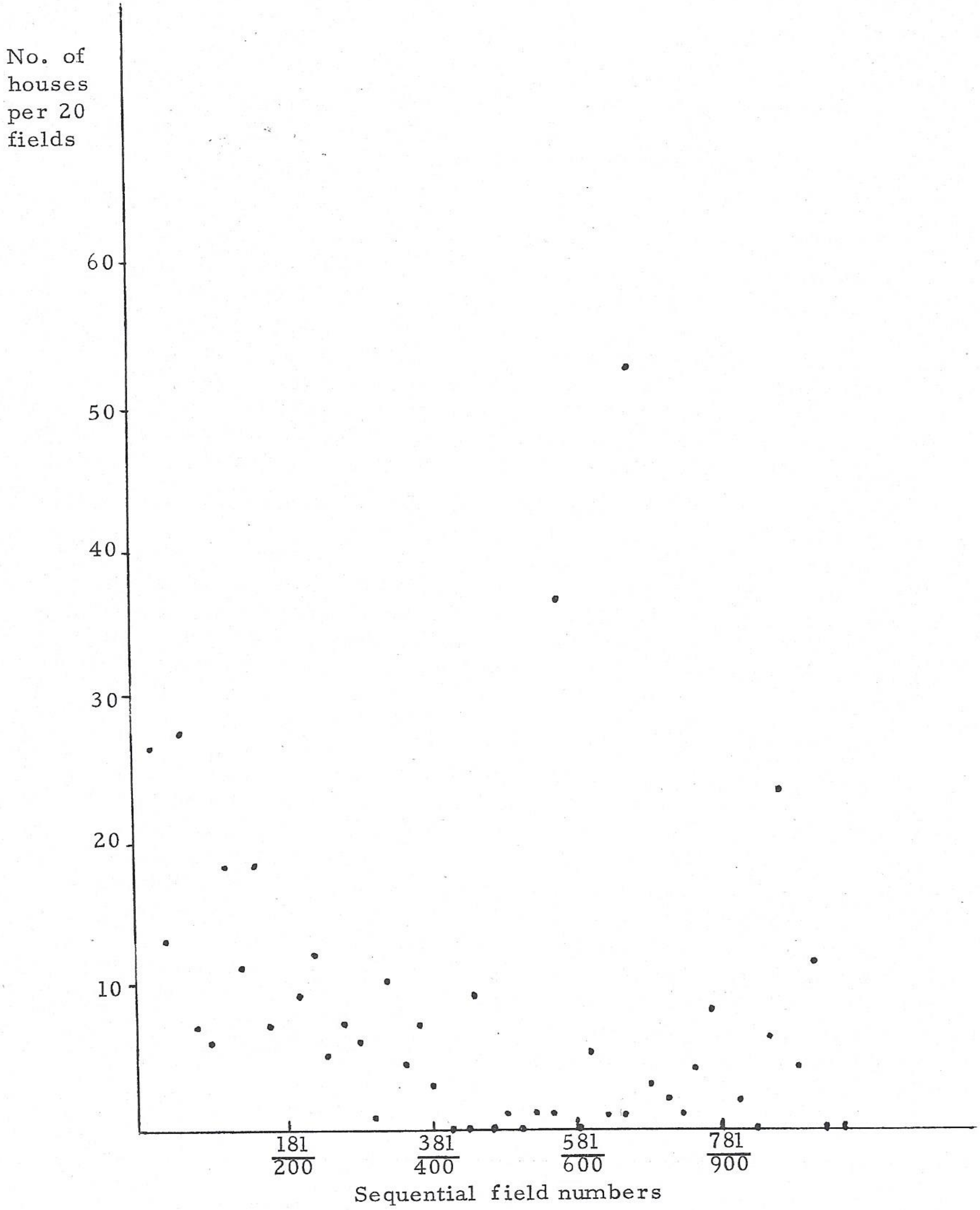
If one examines Figure 7b., two facts are immediately apparent. First, the amount of land use patterning as one moves through space follows a cyclical pattern similar to a sine wave. Second, the size of the oscillation increases for the first two waves or 240 fields and then decreases for the next four waves. Comparing Figure 7b. to Figure 2, one sees that the ecological transition not only demarcates the separation between the increasing and decreasing oscillation, but it corresponds to the greatest amount and variability of the amount of land use patterning.

In short, it is clear that in the area of greatest ecological diversity, the transition, the amount and variability of land use patterning is greatest. As one moves further into the more homogeneous (less diverse) zones, the amount of land use patterning and the amount of variability in patterning decreases. This is exactly what is suggested by the hypotheses and is what is expected if land use patterning is a cultural mechanism to help maximize production and stability in a variety of ecological situations.

Postscript: Hedging the Author's Bets:

The author wishes to hedge his bets two ways. First, I wish to point out that these distributions might be caused by other variables. One of the most obvious would be suggesting that land patterning is a function of the settlement pattern. Figure 10 shows the density of housing along the transect. There is no obvious relationship between land use patterning (Figure 7a. and 7b.) and housing density (Figure 8). Second, this theory and test case was based upon generally accepted ecological theory developed in the last 20 years by Robert MacArthur and others. However, it should be noted that a new book by Robert May entitled Stability and Complexity in Model Ecosystems (1973) has stood the more traditional theory on end. One of his critical arguments follows.

Figure 10
Settlement Pattern Data



> "The central point remains that, if we contrast simple few-species mathematical models with the analogously simple multi-species models, the latter are in general less stable than the former . . .
>
> "This straightforward mathematical fact contradicts the intuitive verbal arguments often invoked . . ., to the effect that the greater the number of links and alternative pathways in the web, the greater the chance of absorbing environmental shocks, thus damping down incipient oscillations. The fallacy in this intuitive argument is that, the greater the size and connectance of a web, the larger the number of characteristic modes of oscillation it possesses: since in general each mode is as likely to be unstable as to be stable (unless the increased complexity is of a highly special kind), the addition of more and more modes simply increases the chance for the total web to be unstable . . .
>
> "On the other hand, the balance of evidence would seem to suggest that, in the real world, increased complexity is usually associated with greater stability . . .
>
> "There is no paradox here.
>
> "One facet of the explanation can be that, although increased complexity makes for a more unstable system, it is advantageous on other grounds . . . if there is a generalization, it could be that stability permits complexity."

Our model is only partially dependent upon "the stability diversity axiom." It is not critical for this paper that complexity causes stability (the traditional viewpoint) or that stability permits complexity (May's viewpoint). In either case, the cultures will attempt to use land patterning as a mechanism for maximizing both invader production and probability of long term success (specialized types of decreased diversity and increased stability).

REFERENCES

Elton, Charles S. 1958. The Ecology of Invasion by Animals and Plants. London: Methuen Press, p. 181.

May, Robert. 1973. Stability and Complexity in Model Ecosystems. Princeton University Press.

AGRICULTURAL DISTRIBUTION IN GUANAJUATO

Thomas Sagehorn

Archaeological sites are subject to continuous modification by man. Therefore it is necessary to study man's effect on the present environment as well as the prehistoric changes in the environment in order to place archaeological data in the proper cultural context. Because the primary modification in the environment surrounding the Guanajuato sites is agriculture, three models were developed to better define the contemporary agricultural systems operating in the site-cluster area.

The Bajio region near Leon is generally characterized as an extremely fertile and productive region of Mexico. However, as one travels through this region it becomes apparent that certain areas, most notably along the hills that flank the valley, exhibit a subsistence or marginal type of agriculture. Next to the cluster of excavated sites, and in particular, adjacent to site-19, an ejido (subsistence) farming community called Cañada de Alfaro exists with a population of 450. Approximately 5.7 kilometers north of this village the regional market is located. This major market area, Leon, has a population of 364,990. The village of Cañada de Alfaro is located at the flanks of hills. Leon, while also located near the hills, is nearer the valley-center such that these population centers represent an excellent test case to evaluate some effects of environmental and social variables on field location, productivity, and other factors that influence the 'cash-crop versus subsistence-crop' decisions a farmer makes in this area.

The aerial photographs used in this study cover an area of 128 square kilometers (see the 'Agricultural Land Map' on page 81 for the organization of photographs). A systematic analysis of 'total land under the cultivation,' number of fields per grid-unit, transportation networks, and variability between fields according to 'total land under cultivation' (techniques explained later in the article) was carried out with respect to the specific requirements of each model.

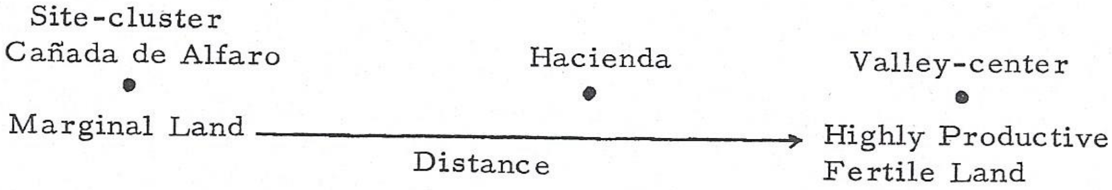
Agricultural Models for Cañada de Alfaro and Leon

Model One:

This model hypothesizes that there should be highly marginal land in the site-cluster area due to the ejido farm's low productivity. The model further contends that low productivity results directly from mutually reinforcing political, historical and economic factors. From the Codigo Agrario y Ley de Colonization (a government publication that delineates legal requirements for agricultural activity in Mexico), it is known that an ejido farm collective cannot extend beyond a 7 kilometer radius of the ejido center. Cañada de Alfaro, located adjacent to the site-cluster, is a community of farm-workers who work at subsistence levels. The ejido farm is characterized by individually tilled, small, subsistence plots. In these farm units it is also assumed that mechanization is not widespread and agricultural technology is low.

When expropriation of hacienda land occurred in Mexico, the legislative codes (e.g. Codes of 1934 and 1942) assured that the former landowner could retain the more fertile land to cultivate. In the Cañada de Alfaro area the ejido land is located near the hills, away from the fertile valley center (see Figure I below). The haciendado (the landowner), in short, offered the poorest quality land for expropriation and retained the best irrigated land surrounding the casco, the center of the estate where the more fertile soil is found.

Figure 1



This model also contends that economic factors inhibit the growth of ejido farm technology and the ejidatarios (the ejido farmer) ability to acquire more land (possibly near the central valley). The ejido farmer is incapable of countering the use of marginal land and low productivity, because credit is difficult to obtain. Carr (1969) points out that the private banks never favor small-scale agricultural credit. The Banco Nacional de Credito Ejidal only offers the ejidatario credit on the security of his crop rather than on his land. However, the land is collectively owned so that only ejidatarios coming together as collectives can get credit. Belshaw (1967) contends that the lack of social cohesion inhibits the cooperation necessary to obtain credit. In the village case of Huecorio, a village Belshaw studied, located 110 miles due south of Leon, even small groups of 10-20 farmers would not pool their resources and apply for credit since none were willing to accept the collective responsibilities of an immediate debt and undefined returns.

As a result of (1) political and socio-economic restraints placed on the ejido farmer, and (2) the highly marginal farm land in the site-cluster Cañada de Alfaro area, two other subsistence farming characteristics can be seen to inhibit agricultural production:

1. It is possible that an innovation will enable the farmer to produce more corn in place of supplementing his crop with purchases, with the effect of releasing sufficient cash from other activities to cover the cost of innovation. Belshaw maintains that this type of logic ignores the fact that the cash income arrives largely in the summer from vegetable crops

(authors note: if cash income arrives at all). At this point in the season all accumulation of corn has been consumed. Consequently, the capital is needed to support the family until the following corn harvest in December. In short, economic conditions define the action that the farmer takes. In the Cañada de Alfaro area, characteristics of subsistence farming impose a heavy penalty for failure whenever an attempted innovation does not succeed. A failure which places the farmer below the margin of subsistence or in debt with a local creditor could prove counterproductive in the long-run.

2. Mellor (1968) contends that even if ejidatarios are motivated to change and innovation is profitable, it is necessary that the individual himself participate in the net increase in wealth which accompanies successful innovation. Whether the source of capital is a local creditor or the comparatively wealthy inhabitant of the near-by hacienda, in the ejido or share-cropping economy (both exist in the site-cluster area), the farmer has little control over the benefits of capital investment. It is assumed that capital is scarce in the ejido system and that capital is highly complementary with other inputs.

This model maintains essentially that highly marginal land within at least a 7 kilometer radius of the ejido center is due to mutually reinforcing political, historical, and economic factors specific to the area. These restraints also create a relatively static environment that prevents the ejidatario from either moving to a more fertile land or gaining the capital resources to develop a more technologically advanced agricultural environment (i.e. to create an economic surplus to invest in, and benefit from, technical innovations, and/or establish a strong economic base to influence and possibly restructure the political and economic institutions that restrain growth).

Test Implications:

1. According to the basic assumption that ejido farms have typically small and fragmented plots, the model predicts that within an approximate 7 kilometer radius of the village, the plots should be highly concentrated and have smaller dimensions as opposed to fields near the valley-center. There should be a gradient effect when plot size is graphed moving from Cañada de Alfaro toward the valley-center and Leon.

2. If the plots are fragmented and located in farm-land of marginal utility, then the total land under cultivation should be highly variable going across fields radiating from the site-center.

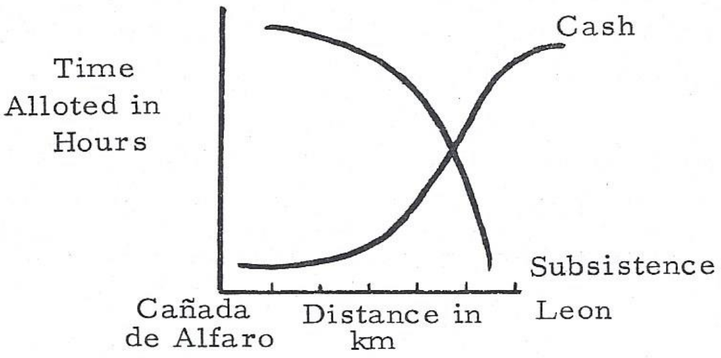
3. There should be physical characteristics in the environment indicating that the farmer in the village lacks an economic surplus to counter the economic and political restraints on farm productivity. In this case, transportation networks will be used as an indicator of the

economic status of the farmer. In the ejido area, one would expect the transportation routes to be either trails and rural roads as opposed to the more modern transportation networks, such as paved roads, major highways, etc., near the valley-center and Leon.

Model Two:

This model hypothesizes that a farmer makes a decision at any one location whether to grow cash-crops or subsistence-crops. Acknowledging Model One's assumption that there should be a high market demand for agricultural products in Leon, this model predicts that a farmer will want to grow cash-crops as close as possible to the market area. Since the village is classified as an ejido, it can be assumed that the village has subsistence crop needs. Assuming that there are economic and physical restraints on the subsistence farmer (i.e. lack of capital to acquire trucks or hire labor and a distance factor that inhibits growing crops beyond a point attainable by walking from the village), this model predicts that the farmer will want to grow subsistence crops as close as possible to the place of consumption (in this case, the Cañada de Alfaro area). Because of these restraints placed on the farmer as to the location of his plots, the model further establishes that a farmer will grow subsistence or cash-crops according to a finite number of hours designated for transportation to the market. If one assumes that the subsistence farmer grows crops up to 3 1/3 kilometers outside the village area, then the distance to solution/market is 2 to 1. At a point 3 1/3 kilometers outside of Cañada de Alfaro, going through space toward Leon, it is predictable that subsistence-crops be grown in this area and that beyond this point, cash-crops will be grown. For instance, as one nears the regional market, Leon, a fewer number of man-hours are required to transport cash-crops to the market. Although the cash-crop is grown nearer to Leon (the crop destination), the farmer who is based in Cañada de Alfaro must typically travel the distance by foot or burro thus increasing the number of man-hours invested. Graph 1 below illustrates this relationship between distance to each respective market and time alloted for transportation:

Graph 1



From this graph it is apparent that transportation cost (in terms of hours) are maximized approximately 3 1/3 kilometers outside of Cañada de Alfaro and 1 2/3 kilometers outside of Leon. At this point, transportation costs, from the subsistence farmer's point-of-view, are prohibitive if the farmer wishes to engage in subsistence-crop agriculture since he can only designate a certain ration for transportation (in terms of hours).

Test Implications:

1. If plot size is used as an indicator of crop-type (subsistence or cash) and one assumes that subsistence plots are smaller and fragmented, then the size of plot should increase the nearer one comes to the regional market, Leon. Specific elements of the model require that plot size increases dramatically approximately 3 1/3 kilometers outside the village of Cañada de Alfaro.

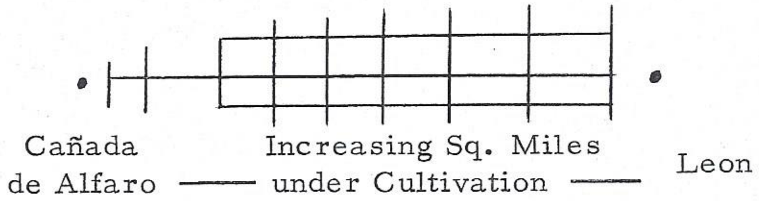
2. If cash-crops have larger plots and are closer to the regional market, there should also be less variability in the total square miles under cultivation in this area. Travelling the reverse course toward Cañada de Alfaro, there should be a high degree of variability in total land under cultivation.

3. As in Model One, there should be a pattern to the type and spatial orientation of transportation networks. In an area where subsistence crops are grown one would expect an abundance of trails and rural roads (dirt or gravel). Again, one would expect a more advanced (not implying greater utility) system of transportation in regions where cash-crops are grown.

Model Three:

This model hypothesizes that any variation in the total square miles under cultivation in the area should correspond to the proximity of the regional market, Leon. From socio-economic and housing characteristics of both population centers it can be inferred that there is a multiple-goods market demand for agricultural products grown in the local area (see Tables 2 and 3 for comparative socio-economic and housing comparatives between the two locations). Since the village of Cañada de Alfaro is located adjacent to the site-cluster area, this model bases its predictions on an assumption that individual farmers will grow crops as close as possible to the market center. In short, from the perspective of a farmer, the location of farm plots, and hence, the area of highest agricultural production, is a function of distance from the market area. From this assumption, it follows that the total square miles under cultivation should also increase as one nears the perimeter of Leon. An important condition to this model requires that agricultural production be concentrated between the two geographical points, Cañada de Alfaro and Leon, as opposed to an equal distribution of total square miles under cultivation in the area covered by the aerial photographs. Figure 2 below illustrates this relationship between proximity of the regional market and the total square miles under cultivation:

Figure 2



Test Implications:

1. The model predicts that there should be a gradient when total land under cultivation is plotted starting in Cañada de Alfaro and terminating (at the highest level) near the perimeter of Leon.

2. The model also implies that the agricultural land near the regional market is highly desirable. If this is true, there should be a low degree of variability of total land under cultivation around the perimeter of Leon.

3. Going through space in any direction other than north (or toward Leon), the model requires that the total land under cultivation decrease. This behavior would support the model's condition that production be concentrated between the two geographical points, Cañada de Alfaro and Leon.

4. When one travels through space in any direction other than toward Leon there should be a greater variability in total land under cultivation. It follows that there should be lower figures for land under cultivation as opposed to higher figures between Cañada de Alfaro and Leon.

Test Results

Square Kilometers of Land under Cultivation per Photograph:

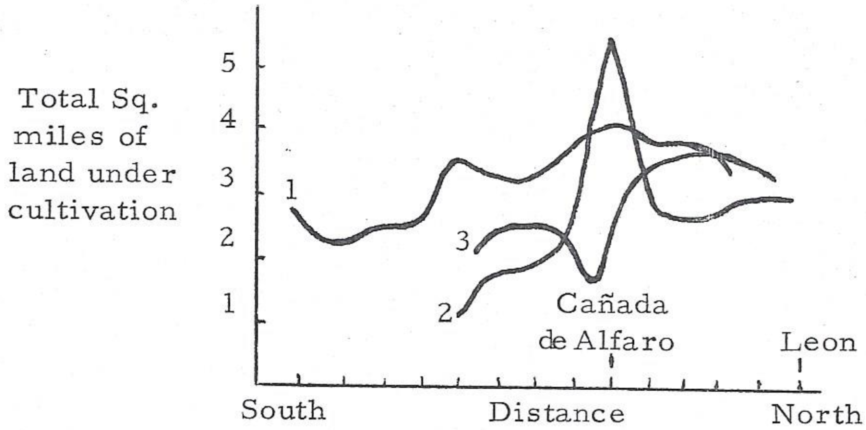
Graph 2 was plotted to show the total square kilometers under cultivation as one progresses north from the base of the series of photographs.[1] Each line represents one series of photographs. Line 1 shows that totals per photograph for series 37, photographs 57 through 46 (following the south to north progression of photographs on the 'Agricultural Land Map'). Line 2 represents series 36, photographs 6 through

---

[1] See Table I for the total square kilometers under cultivation per photographic unit.

18. Line 3 represents series 34, photographs 9 through 17.

Graph 2



Two characteristics of the graphs are particularly important to the models proposed. The first pattern that develops is that the totals for land under cultivation generally increase as one nears the northern area of photographs. Second, there is erratic behavior of total land under cultivation near the Cañada de Alfaro area. Line 2, which represents the land nearest the ejido and the valley-edge, increases dramatically as a result of a total of 5.7 square kilometers under cultivation in photograph 36-13. At approximately the same geographical location in photograph 34-12 , there is a low total of land under cultivation. In both lines, however, an upward trend develops after this decrease and levels off at approximately the same total as Line 1.

Delta Fractions in Land under Cultivation per Photograph:

To test for degrees of variation in total land under cultivation per photograph, a series of delta fractions were calculated. Table 1 shows the total square miles under cultivation in each photograph. Using each series of photographs as arbitrarily defined units of space, the delta fractions for every two consecutive photographs can be calculated.[2] The formula used was $\frac{x-y}{y}$ where y = the southern-most photograph of the two photographs and x = the northern photograph. The delta fractions can be used as an indicator of variability of land under cultivation in the area covered by the photographs. For example, in column 1, photograph series 37 starting at the base, delta fractions progress as such:

---

[2] Each unit is an equal spatial area for comparison with other units in the same series. The delta fraction measures the percentage change in the amount of cultivable land between each pair of contiguous photographs.

	Photographs	Land under Cultivation	Delta Fraction
North	37-54	2.6 square km	
	37-55	2.6 square km	.00
	37-56	2.1 square km	.24 fraction increase
South	37-57	2.8 square km	-.25 fraction increase

The complete delta fraction results are as follows:

Photos	Delta Fraction	Photos	Delta Fraction	Photos	Delta Fraction
37-46		36-18		34-17	
-47	-.08	-17	.00	-16	-.11
-48	.00	-16	.04	-15	-.03
-49	.09	-15	.04	-14	.03
-50	-.10	-14	-.07	-13	.17
-51	.18	-13	-.49	-12	.80
-52	.00	-12	1.11	-11	-.33
-53	-.11	-11	.50	-10	.00
-54	.42	-10	.00	-9	.14
-55	.00	-9	.64		
-56	.24				
-57	-.25				

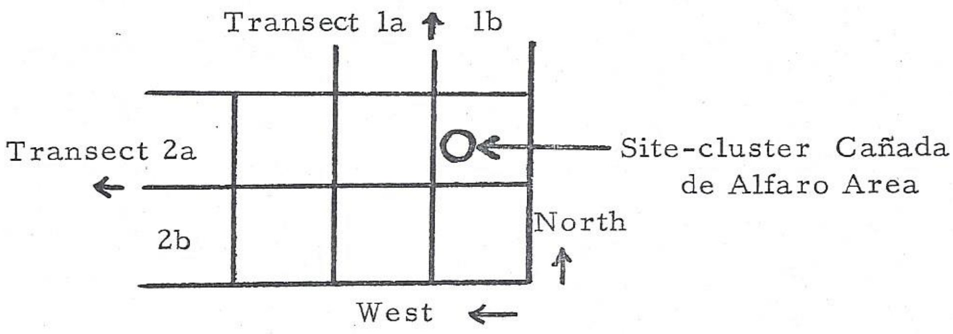
Graphs 3a, 3b, and 3c (found on pp. 79, 80) show these figures plotted on a graph. The points plotted are adjusted taking into account the lack of spatial continuity between the photographs travelling east to west across the base of the map.

From the results of the 'delta fraction variation,' it is apparent that a pattern develops for total land under cultivation travelling northward from the base of the photographs. In all three series of photographs, the fractions appear to oscillate with amplitudes between highs of .42 (graph 3a), 1.11 (graph 3b), and .80 (graph 3c) and lows of .08, -.09 (graph 3a), .04 (graph 3b) and .03, -.03 (graph 3c). The behavior of the oscillation also follows a pattern that corresponds to major geographical locations discussed in the models. Following the spatial course of the photographs, particularly high delta fractions can be identified south of any point west of the site-cluster, Cañada de Alfaro area. However, as one nears a point parallel to Cañada de Alfaro and progresses northward to Leon, the amplitude of the oscillation damps and continues to exhibit low delta fractions until the series of photographs end.

Plot Size

To find an approximation of plot size as one nears the valley-center (west of Cañada de Alfaro) and Leon (north of Cañada de Alfaro) a grid pattern was super-imposed on the aerial photographs. The photographs used for this test were 34-13 through 34-17 and 36-14 through 36-18.

Each grid-unit was .63 kilometers by .63 kilometers and contained .40 square kilometers of land. Two transects were drawn from the Cañada de Alfaro area with grid-units adjacent with the transect and contiguous with each other. There were a total of 28 grid-units with each transect equalling a distance of 5 kilometers. The grid-pattern looked as such:

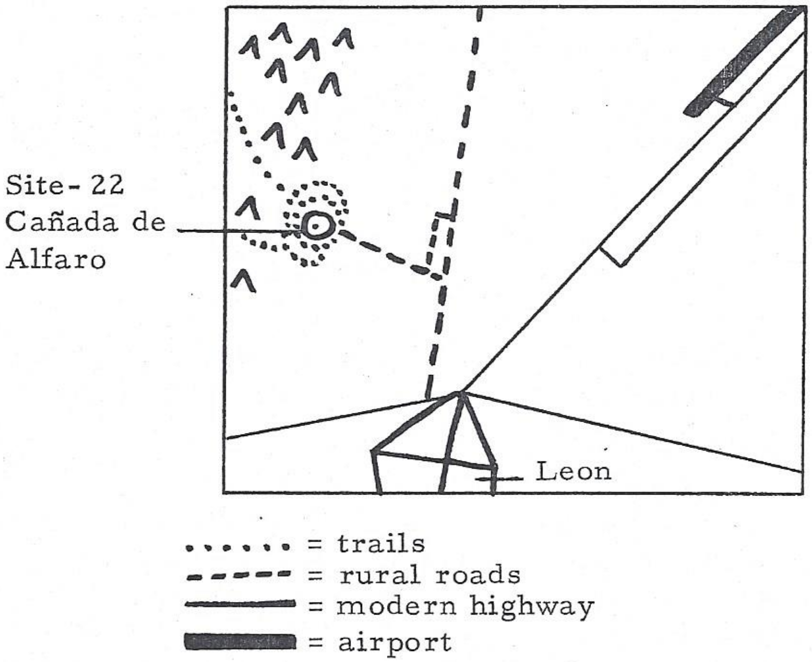


After this grid-pattern was super-imposed on the photographs the number of fields per grid-unit were counted. With the number of fields known, these figures served as an indicator of field size, recognizing that some interference is to be expected from dwellings and roads.

Graphs 4a, 4b, 4c, and 4d (located on p. 80) show the number of fields per grid-unit for the series of fields. Geographical points of reference have been marked on the x coordinate of each graph for comparing the number of fields per grid-unit. Two characteristics of the graphs are relevant to the models being tested. First, the decreasing number of plots going either west or north of Cañada de Alfaro indicates that plot size increases steadily as one nears the valley-center or the city of Leon. Second, there appears to be a dramatic increase in number of plots per grid-unit as each transect passes through Cañada de Alfaro. Although Graph 4d is less dramatic in its steady decline in fields per grid-unit, this particular series of units is located approximately 1.2 kilometers south of the site-cluster, Cañada de Alfaro area and initially travels through hills that flank the valley. A third characteristic of field size is apparent when one observes the pattern of field dimension and location. Within the first two groups of contiguous fields in the grid-pattern (transect 2a and 2b) fields have highly irregular shapes (near-circular, triangular and oval). It is worth noting that these fields are located near the hills that surround Cañada de Alfaro on 3 sides.

Transportation Network Map

Along the flanks of the hills, as mentioned throughout the article, subsistence agriculture predominates. From the mountainous areas near the site-cluster Cañada de Alfaro area to the valley floor one sees a transition in the pattern of transportation networks. A 'Transportation Map' which includes geographical formations and population centers, illustrates this transition:



The community of Cañada de Alfaro has limited access to Leon, the regional market, through the use of narrow rural roads. In the specific area of Cañada de Alfaro there are many trails concentrated in the village area with two trails leading back into the mountain area. Toward the center of the valley one sees that at least 4 major highways converge at the city of Leon. The highway that runs parallel to the rural road eventually turns into a 4-lane highway about 7 kilometers outside of Leon. Adjacent to the highway is an airport.

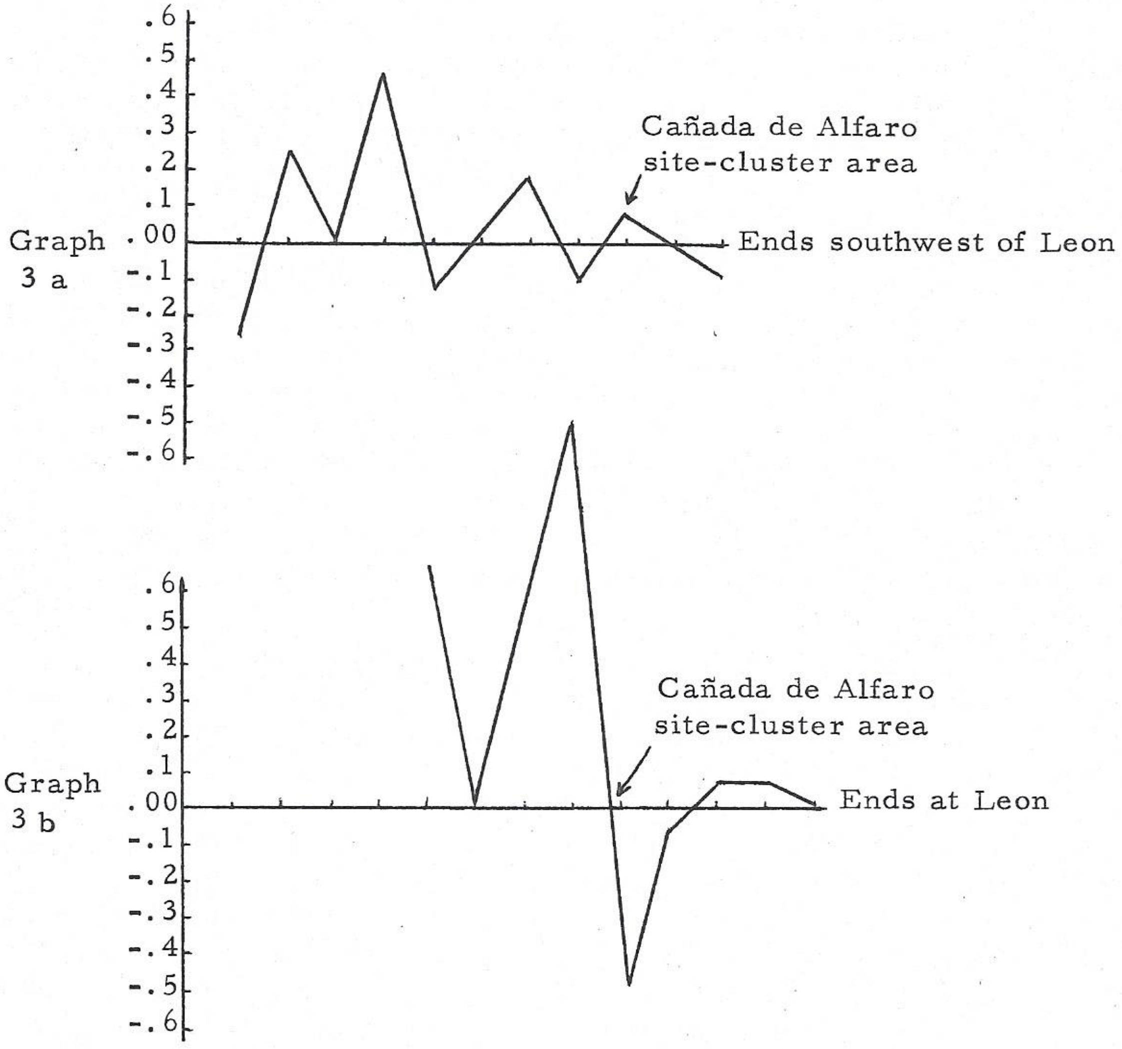
Conclusion

Model One attempts to analyse the political, historical, and economic restraints placed on the ejido farm collective. The model's prediction that plot size and fragmentation are aberrant in regard to other agricultural areas near Leon and the valley-center is supported by test results. It is true that field size increases going north or west of Cañada de Alfaro and that there is a high degree of variability of total land under cultivation near Cañada de Alfaro. However, the field numbers per grid-unit decline rapidly at a point approximately 1 kilometer outside of the village in both directions (west and north) of the transects. This information suggests that the ejido does not have geographical boundaries that extend to the legal maximum of 7 kilometers. Rather, the ejido boundaries probably end 1 to 2 kilometers outside of the village. This condition is also supported by the results of the transportation network study. Although this particular test is not comprehensive in quantitative terms, the test supports the notion that there is a form of subsistence farming existent in the site-cluster area. The concentration of trails and rural roads within the small geographical area of the ejido makes this test result highly complementary with the 'delta fraction' and 'plot size' results.

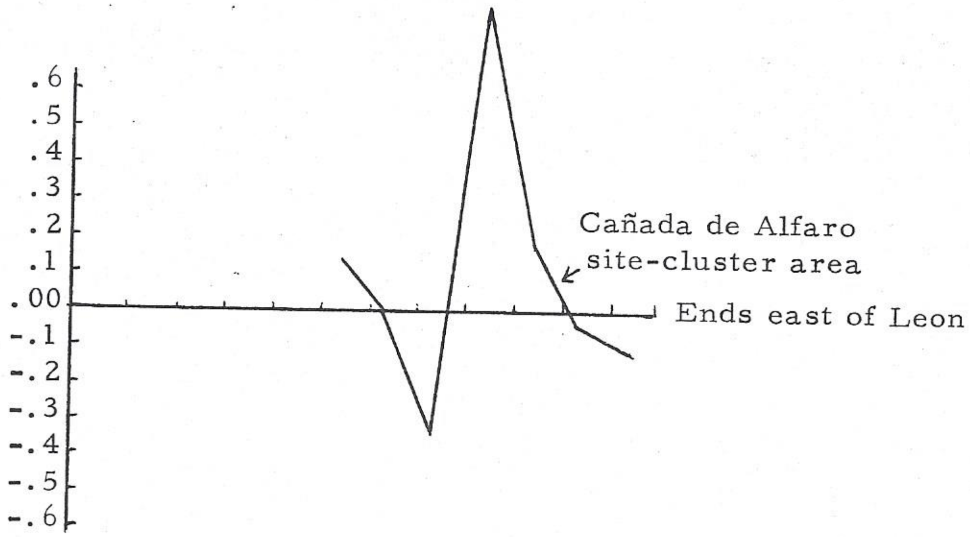
This understanding of the geographical boundaries of the ejido village and land also effects the accuracy of Model Two. This model predicted that transportation costs would prohibit the subsistence farmer from growing cash-crops beyond a point of 3 1/3 kilometers outside the village. Although test results clearly contradict this prediction, it is also apparent that the model is inaccurate for a more political reason. The assumption that the farmer has a choice as to where he will grow his crops is erroneous. In fact, the farmer cannot legally make his decision beyond the geographical boundaries of ejido land as implied by law. Model predictions in regard to (1) size of subsistence farm plot, (2) increasing plot size as one nears the regional market, (3) variability between defined units of cultivated land, and (4) a transition in transportation networks, have a great deal of value in understanding the environmental factors influencing cash-crop versus subsistence-crop "decision" that a farmer must make. However, results do not support the model's specific prediction concerning the subsistence-crop versus cash-crop transportation costs (in terms of hours) ratio.

Model Three is a deceptively complicated hypothesis since it seems intuitive that agricultural production and total land under cultivation should increase the closer one comes to a large market with diverse needs. This model assumes that production is concentrated in a relatively local area and that any land outside this area (e.g. in the 2a and 2b transect area) must have unusually low totals of cultivated land. In fact, the model's assumptions are generally supported by test results as total cultivated land variability between units/photographs decreases according to the proximity of the market, Leon. When total square miles under cultivation figures are considered, the model's prediction is not supported. It should be mentioned that the decline might be considered negligible due to minor interferences from dwellings and roads that intersperse the periphery of the city-limits. In any case, generally high totals for land under cultivation prevail in the perimeter area compared to points father south in the valley, particularly along the flanks of the hills. The model's major deficiency (and a deficiency associated with Model Two) is that it assumes a clear land-use relationship between the regional market, Leon and Cañada de Alfaro. The model does not incorporate into its assumptions a condition that other factors might influence the location and size of fields. However, the model's theoretical orientation does have gravity. According to the proximity of the valley-center from any point west of Cañada de Alfaro, plot size increases, there are higher figures for land under cultivation, and low delta fractions between units of land.

Delta Fractions Graphs

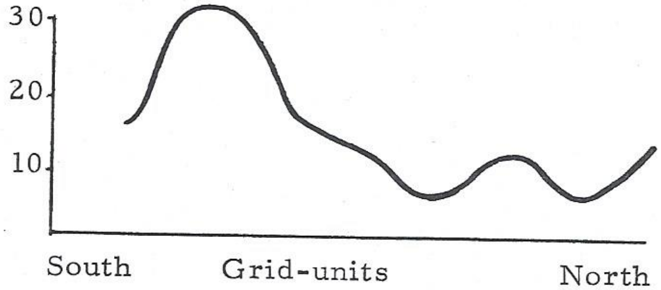


Delta Fractions Graph 3 c

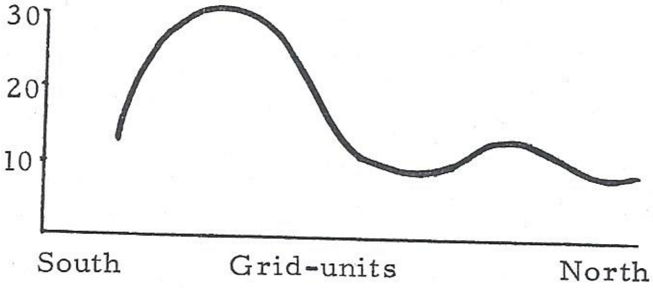


Numbers of Plots per Grid

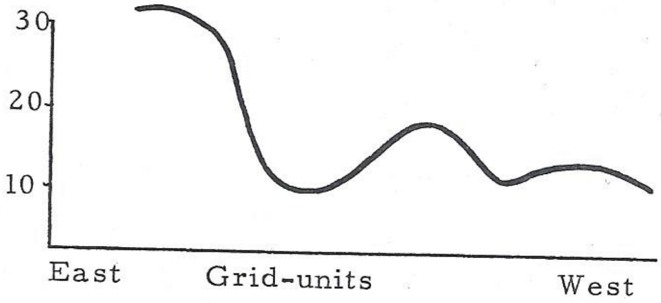
Graph 4a Transect 1a



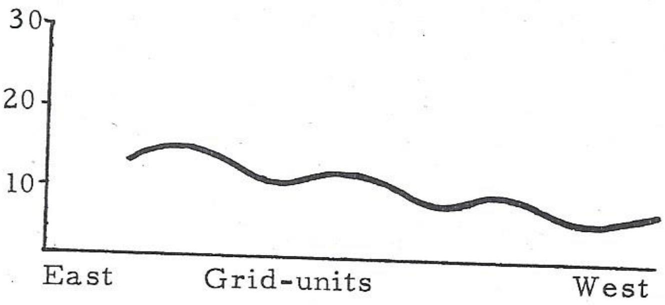
Graph 4b Transect 1b



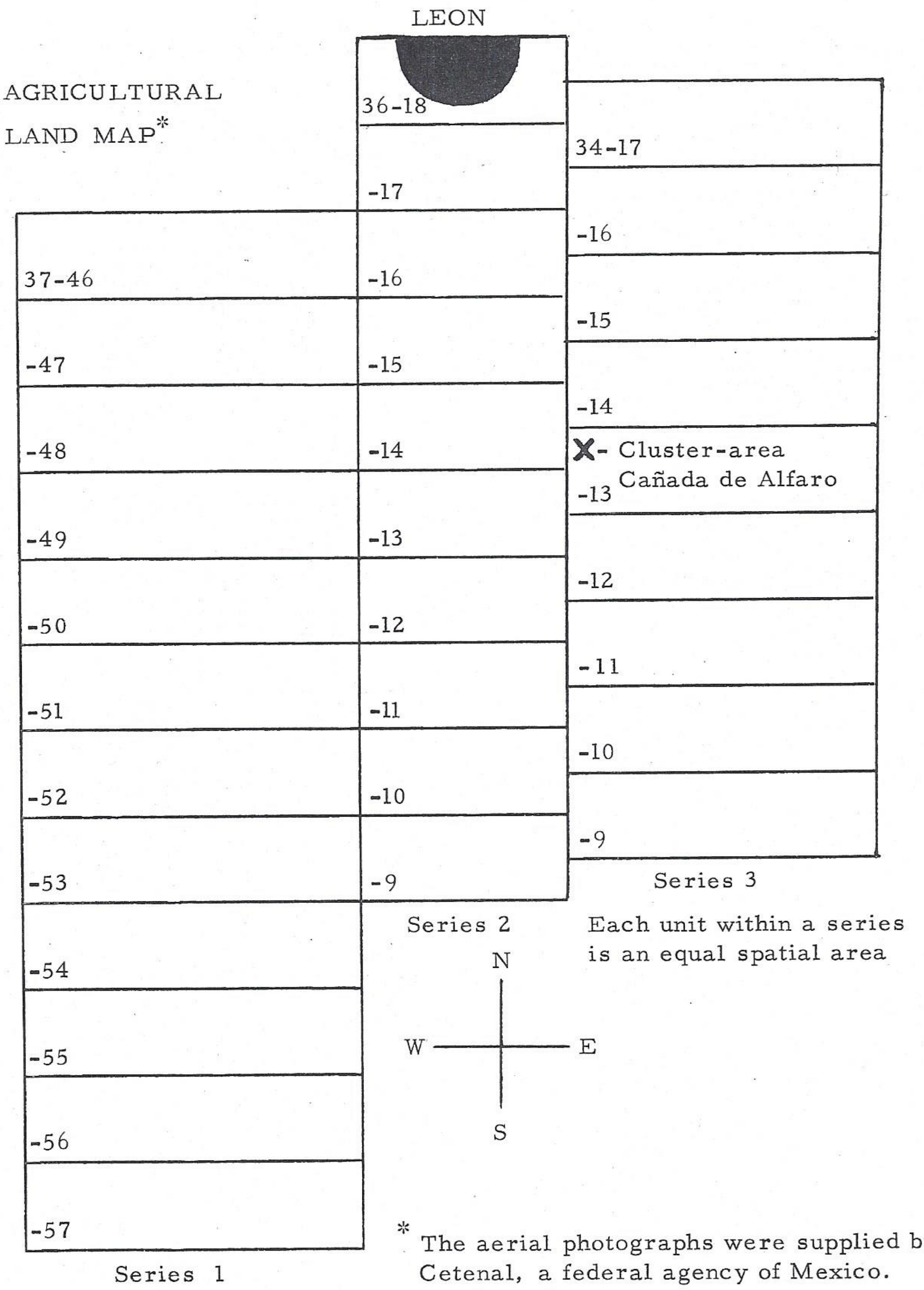
Graph 4c Transect 2a



Graph 4d Transect 2b



AGRICULTURAL LAND MAP*



Each unit within a series is an equal spatial area

---

* The aerial photographs were supplied by Cetenal, a federal agency of Mexico.

APPENDIX

1. Table 1 shows the square kilometers of land under cultivation on each photograph when they are arranged according to the order on the 'Agricultural Land Map.'

Table 1[*]

Photo	Cult. Sq.km	Photo	Cult. Sq.km.	Photo	Cult. Sq.km.
37-46	3.6	36-18	2.9	34-17	3.1
37-47	3.9	36-17	2.9	34-16	3.5
37-48	3.9	36-16	2.8	34-15	3.6
37-49	4.3	36-15	2.7	34-14	3.5
37-50	3.9	36-14	2.9	34-13	3.0
37-51	3.3	36-13	5.7	34-12	1.6
37-52	3.3	36-12	2.7	34-11	2.4
37-53	3.7	36-11	1.8	34-10	2.4
37-54	2.6	36-10	1.8	34-9	2.1
37-55	2.6	36-9	1.1		
37-56	2.1				
37-57	2.8				

2. The margin of error on any figure in Table 1 is no greater than 2 1/2 per cent, or in some cases less. The two factors that contribute to the margin of error are:

a. the difficulty associated with fitting photographs together and measuring them for land under cultivation, and

b. the minor scale differences in some photographs, related to a variable camera angle and airplane altitude.

3. Rogers (1968) points out that the degree to which farmers are efficiency-minded, market oriented and economically "rational" (quotes added), depends in a large part on the degree of modernization of the village. Tables 2 and 3 below show the socio-economic and housing characteristics of the city of Leon and the village of Cañada de Alfaro, located approximately 5.7 km southeast of Leon and next to the site-center. This information is relevant to the models presented in this article as the model's assumptions are contingent upon significant population, economic, and agricultural production differentials between Cañada de Alfaro and Leon.

---

[*] The study to measure the totals of land under cultivation was completed by James Pendergrass in May of 1973. The figures was arrived at by using a compensating polar planimeter, a device for accurately measuring irregular surface areas.

Table 2

Comparative Socio-economic Characteristics of the Population (expressed in percentages):

# of People	Econ Active	Agric	Indust	Commerce	Literacy
Alfaro 450	28.0	63.5	23.0	5.6	22.3
Leon 364,990	26.9	4.9	53.9	34.4	79.0

Table 3

Comparative Housing Characteristics of the Population (expressed in percentages):

# of Houses	Private	Outside water	Inside water	Pipes	Non-Dirt floors	Elect'y	Radio	T.V.
Alfaro 69	18.8	85.5	5.8	2.9	5.8	...	72.5	...
Leon 54,625	55.7	66.2	9.1	68.1	85.9	85.8	85.5	45.4

Note: The information in Tables 2 and 3 was found in:
IX Censo General De Poblacion 1970, volumen 1;
A Guascalientes A Guerrero, 1973.

BIBLIOGRAPHY

Belshaw, Michael Horace. 1967. A Village Economy: Land and People of Huecorio. Columbia University Press.

Carr, Raymond. 1969. "Mexican Agrarian Reform 1910-1960." Agrarian Change and Economic Development, the Historical Problems. London: Methuen and Co., Ltd.

IX Censo General de Poblacion 1970, Volumen 1; A Guascalientes a Guerrero, 1973. Estados Unidos Mexicanos, Secretaria de Industria y Comercio Direccion General de Estadistica.

Leyes Mexicanas. Codigo Agrario y Ley de Colonizacion. 1960. Editorial Divulgacion, Mexico, D.F.

Mellor, John Williams. 1968. "The Subsistence Farmer in Traditional Economies." Subsistence Agriculture and Economic Development. Aldine Publishing Co., Chicago.

Rogers, Everett M. 1968. "Motivations, Values and Attitudes of Subsistence Farmers: Toward a Subculture of Peasantry." Subsistence Agriculture and Economic Development. Aldine Publishing Co., Chicago.

ARCHAEOLOGY
AND
THE PORTABLE REFRACTION SEISMOGRAPH

Elizabeth Skinner

I. Introduction

A portable refraction seismograph was tested during an archaeological field expedition in Guanajuato, Mexico in the summer of 1973. This paper attempts to analyze the seismographic data and to determine the seismograph's archaeological utility.

The paper has three sections. The first section deals with the theory and use of seismic instruments. The next section explains the methodology of the fieldwork and the method of analyzing the data. The seismograph was used on several sites. On each site linear courses were run, in which data was collected relevant to the subsurface near that course. The raw data consists of a list of seismograph readings (time and distance) for each course. A series of hypothetical underground structures were developed, accompanied by hypothetical time-distance graphs of what the seismographic readings of these cases would look like.

From the hypothetical cases and the real time-distance graphs, interpretations of the actual profile of each site were made. Conclusions were then drawn as to the validity of the use of the portable refraction seismograph for archaeological purposes.

II. The Theory of Seismic Exploration

Basic seismic principles

Seismic methods are based on the fact that "the velocity of propagation of a wave or impulse in an elastic body is a function of the modulus of elasticity, the Poisson ratio, and the density of the material, and that very great differences exist between wave velocities in solid rock and in loose, sedimentary deposits."[1] An impulse travelling through the earth will produce longitudinal or compression waves, transverse or shear waves, and various types of surface waves. In the seismic methods of exploration, it is usually the velocity of the longitudinal or compression waves which is important.

Rocks and many accumulations of unconsolidated sand, gravel, and clay are elastic, and resist an applied stress by a force that is approximately proportional to displacement. Therefore, when disturbed, they oscillate with simple harmonic motion. When one portion of such a medium is displaced, adjacent particles are displaced. As time passes, more and more particles are included in the displaced portion. The result is the advance of an elastic wave through the medium.

---

[1] M.J. Hvorslev, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes. p. 29.

The longitudinal or compression wave

The longitudinal wave is a body wave, that is, it travels through the interior of an elastic medium. It advances by alternating compression and rarefactions, and thus is also known as a compressional wave. It is called longitudinal because the sense of motion of a particle is along the direction of the wave's advance. The symbol P denotes this wave type.

Wave propagation

If a material in which P waves travel with a certain velocity, adjoins another material in which they travel with a different velocity, a wave encountering the boundary between the materials will produce displacements at that boundary which result in the setting up of (1) a reflected P-wave, and (2) a refracted P-wave advancing into the new material. The distribution of the initial energy among the derived waves is determined by the angle at which the wave approaches the boundary and the contrast in elastic properties of the two materials.[2]

The refraction principle

The refraction method is based on the fact that a wave in travelling across a boundary is refracted toward the plane of the boundary when it enters a material which transmits the wave with a higher velocity and toward the perpendicular to the boundary when it enters a material which transmits the wave with a lower velocity.[3]

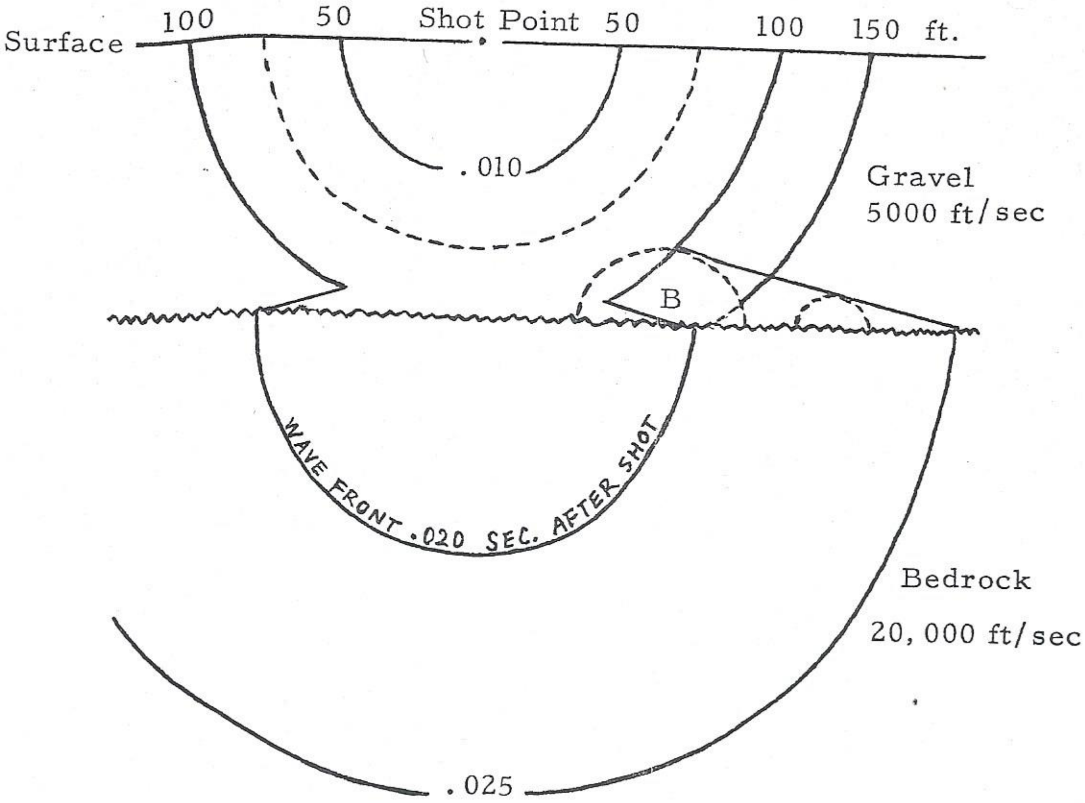
The example below will illustrate how the seismic method operates: There is a wave front in a 2 layer structure consisting of about 80 feet of gravel on bedrock. The wave travels about 5,000 feet per second, in the gravel and about 20,000 ft/sec. in the bedrock. In such a condition a wave front will be an approximate sphere of 50 feet radius .01 seconds after it leaves the shot point. The wave is created by a blow or a "shot" at a particular place and time upon the surface of the earth. About .016 seconds after the shot, it reaches the rock surface. From this point of contact, a wavelet starts into the rock with a velocity of 20,000 ft/sec. At .02 seconds after the shot the wavelet has reached the distance noted, not only vertically but radiating in all directions within the rock, so that even along the gravel-rock contact the wave front has reached the point B (see Figure 1). However, along the boundary the wave in the rock starts a new series of wavelets that emanate into the gravel and are directed to the gravel surface.

---

[2] D.L. Leet, Earth Waves. p. 59.

[3] M.J. Horslev, Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes. p.30.

Figure 1

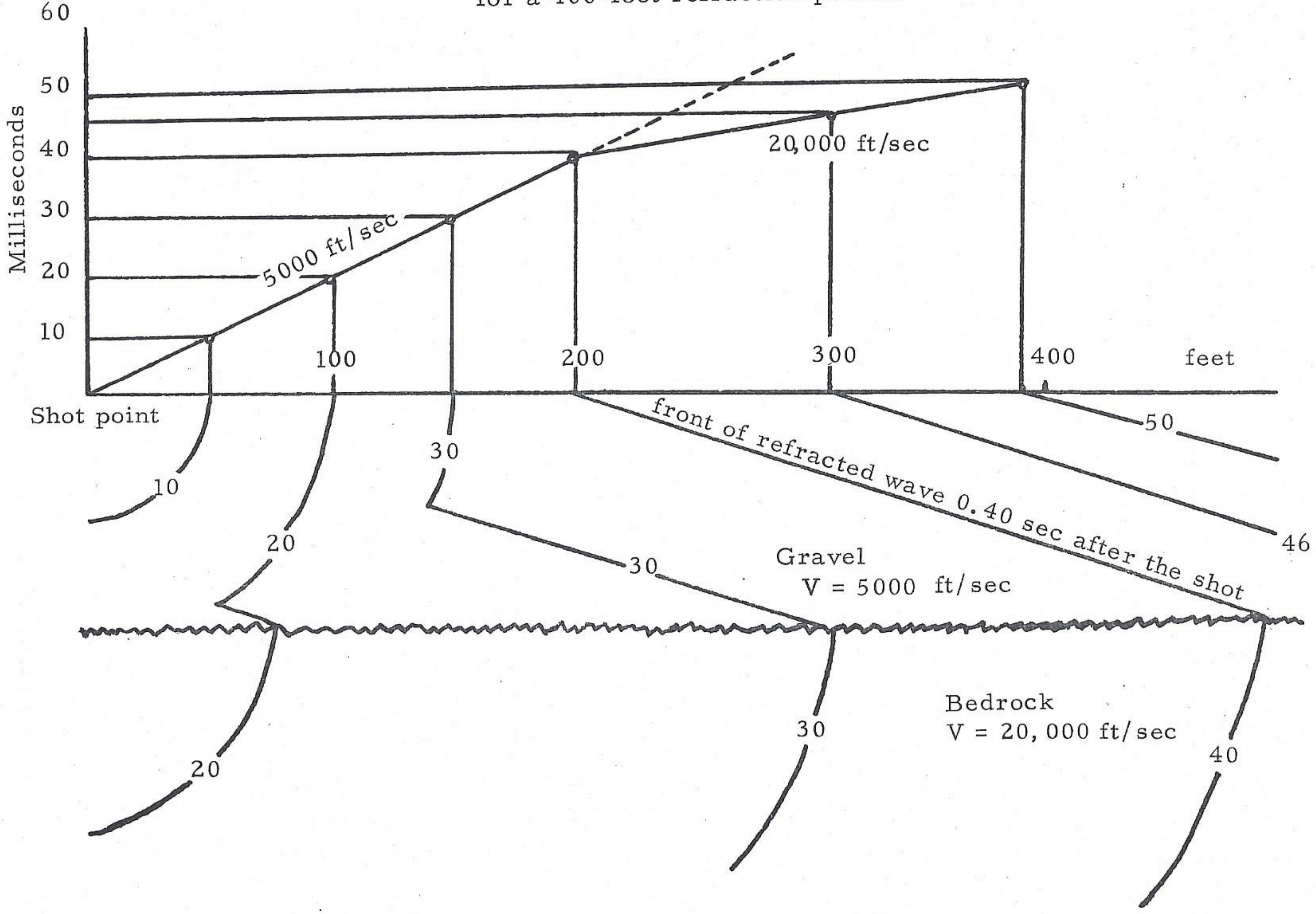


The wave front travels through the gravel on to each instrument at 5,000 ft/sec, but there is a point along the line, or profile, where the wave front refracted from the rock, owing to its higher velocity gained from the rock, will reach an instrument before the direct wave. In the diagram this is a point a little more than 200 ft. from the shot point. Thus the velocity of the materials may be determined; those of the earlier arrivals at the geophone may be computed to be 5,000 ft/sec, the velocity of gravel in the problem, and the later arrivals may be computed to be 20,000 ft/sec, or the velocity of the bedrock. The distance from the shot point to the point of intersection of these two lines is controlled by the thickness of the gravel, and the greater the thickness, the greater will be the distance of the intersection from the shot point.[4]

---

[4] Daniel Linehan, "Seismology applied to shallow zinc research." p. 78 (Figures 1 and 2, after Lenehan's diagram).

Figure 2
Diagram of wave fronts, and the relevant travel-time graph
for a 400-foot refraction profile



III. Basic Soil Mechanics and the Seismic Principle

The use of the seismic method to explore subsurface structures is based on the fact that the velocity of wave propagation differs a great deal in different materials.

Velocity characteristics of different materials

The age of the material through which a given wave propagates is the critical variable determining the wave's velocity. In general, it can be stated that the velocity in unconsolidated materials is low and in consolidated materials it is high. The velocity in new or re-deposited soils is usually much lower than in undisturbed soils. Often, unusually low velocities are recorded in deep fills, especially if they contain refuse, ashes, cinders, and other similar materials. Also very low velocities have been recorded in a mass of loose rock and boulders which contained little or no earth, but in which there was no continuity of structure.

A table has been constructed showing the speed of wave propagation in different materials, and shows in a general way the approximate range of velocities which may be expected (see Table 1). (For a more complete listing, see Shepard, 1939: Table 1.)

Table 1

Velocity Table

Sand and Topsoil	600 - 1,200 ft/sec.
Sandy Clay	1,200 - 1,900 ft/sec.
Gravel	1,600 - 2,600 ft/sec.
Glacial Till	1,800 - 7,000 ft/sec.
Rock Talus	1,300 - 2,500 ft/sec.
Water in Loose Materials	4,600 - 6,000 ft/sec.
Shale	2,600 - 11,000 ft/sec.
Sandstone	3,000 - 9,000 ft/sec.
Granite	10,000 - 20,000 ft/sec.
Limestone	6,000 - 20,000 ft/sec.

When a layer of homogeneous soil overlaps one of higher elastic properties, there will be a critical shooting distance for which the time of travel through the upper layer is just equal to the time of travel over the longer path which penetrates the deeper and faster layer. At this critical distance there will be a break in the time-distance graph to a different slope, which represents the velocity of wave propagation in the second layer. Similarly, when the critical shooting distance for the third layer is reached there will be another break in the graph to a new slope, which represents the velocity of the third stratum.

The above assumes that the path of the seismic wave is vertical from the shot point (or hammer point) to the rock, along the rock to a point directly under the detector, and thus vertical to the detector. This assumption is only useful when dealing with shallow depth determinations.

When the surface of the rock is parallel to the ground surface, the slope of the graph (see Figure 2) will give true velocities. However, when the interface is not parallel to the ground surface, the profile line must be shot from opposite directions to determine the true velocity.

If the rock surface slopes downward from the shot point, the refracted wave has to travel farther to the surface at each successive reading, and the apparent velocity will be slower than the true velocity. If the rock slopes upward from the shot point, there is less distance for the wave to travel and the apparent velocity will be greater than the true velocity. The apparent velocities do indicate the direction and the approximate slope of a rock surface.

IV. The Refraction Seismograph

Principle of the refraction seismograph

The following is a description of the basic one-channel seismograph. This instrument consists of a timing unit, an amplifier, and a display unit, all built into one box. It has a separate power unit, geophone, and a 10 pound sledge hammer. The hammer is connected to a switch, and when the hammer hits the ground, the switch closes and a pulse is fed into the timing unit. After a certain time delay, which is controlled by the operator, a marker appears on a cathode-ray tube screen. The seismic wave is picked up by the geophone, and appears on the same screen. The timing dial is then rotated so that the beginning of the first impulse coincides with the marker. The time delay, which is equal to the travel time of the fastest wave, is then read on the timing dial.

In the field, the geophone is placed at the location where the depth to bedrock is required, and the hammer blows are along a profile at spaced intervals.

The terra-Scout model R-150[5]

The Terra-Scout essentially follows this basic design. It is made up of three parts: the hammer, geophone, and the instrument which records the wave from the geophone on a cathode-ray tube screen, and measures the travel time of the wave between the hammer and the geophone.

---

[5] The portable refraction seismograph used in this fieldwork was a Terra-Scout model R-150, manufactured by Soiltest Inc. of Evanston, Illinois.

The instrument itself consists of various controls: the off-gain, delay, range, test button, intensity, focus, and horizontal and vertical positioning. The gain control increases or decreases the size of the wave on the screen. The delay read-out varies the interval of the time between the hammer blow and the start of the sweep across the screen. The range provides 2 ranges by acting as a multiplier of the delay dial readings. Therefore, this timing read-out can be direct or by the multiplier in milliseconds. It is accurate to ± 0.25 milliseconds from 0 to 250 milliseconds. The test button acts as the hammer switch to produce a sweep across the screen, and is used as a check. The wave display is on a 5-inch cathode-ray tube controlled by horizontal and vertical centering, intensity and focus controls. The tamper, or hammer, has a triggering accuracy of ±5 microseconds and is damped with nitrogen and helium gases. This instrument commonly gives results to depths of 75 feet to 100 feet, and in some areas can be used up to 200 feet in depth.

Problems with and limitations of the refraction seismograph

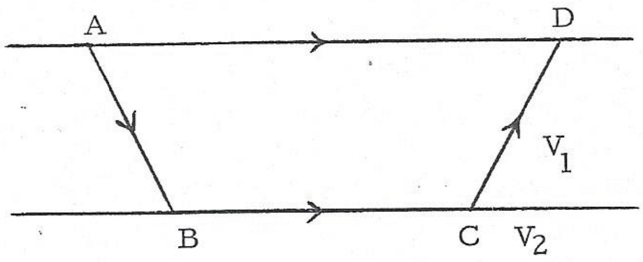
When using the seismic method of investigation, there are numerous problems and limitations of the instrument itself that must be taken into account in the interpretation and analysis.

The seismic refraction method is based on the assumption that the velocity of the seismic waves will increase with increasing depth. A layer which transmits the waves at a lower velocity than the overlying layer cannot be detected or its thickness determined. (In fact, a layer must have a certain minimum thickness in order to be detected at all.) If the masked layer is underlain by a layer of higher velocity than the overlying layer, the resulting graph will be a 2-layer curve with the middle layer absent, but the calculated depth to the lowest layer will be so much greater than the actual depth that any familiarity with the geology of the area will lead to doubts as to the validity of the results. When working in a given area, some of the graphs might show a second layer while on other graphs the layer will be absent or only slightly indicated. If the presence of a second stratum is indicated by some graphs, it is probable that its extent would be general, and it would be logical to include the second phase wherever there is any indication of it. This problem has been dealt with in more detail by Kaila and Narain (1970).

Advantages and disadvantages of the refraction method

The refraction method of investigation is most powerful for reconnaissance in a new area. Records of the first pulse to arrive at the detector can be made for a wide range of source-detector distances. Figure 3 shows the various paths a refracted wave may take:

Figure 3



In addition to the direct wave AD, a refracted wave can travel by the minimum time path ABCD. It is necessary for the lower layer BC to transmit compressional waves faster than the upper layer. At long distances the refracted wave overtakes the direct wave, and can be clearly read because it is the first wave recorded.

The greatest strength of the refraction method is that it allows a picture of the strata to be drawn and provides a velocity for each layer.

One of the limitations placed on this method is that the length of the refraction spread must be many times longer than the depth to the deepest refractor, usually 5 or 6 times.

In order for the refracted wave to return from a layer to the surface, the velocities must increase in each subjacent layer. This incapacitates this method in areas where the upper layer of the ground freezes and masks arrivals to a distance many times the thickness of the frozen layer. In other areas, layers of rock are usually not laid down in order of increasing velocity downwards, giving velocity reversals. A hard thin layer can be sandwiched between low velocity layers, such as clay, and the refracted wave from the thin layer will mask that from the lower velocity layer underneath.

The author is aware of other relevant problems such as "surface interference," "wave dispersion," "groundroll," "reflection problems," "surface regularity," and "weathering." However, space precludes their discussion here. For a complete discussion see Skinner, 1974.

V. Methodology of Seismograph Fieldwork

The decision of which site to seismograph was based on various factors. Seismographing was done on sites previously excavated and on sites where cores were taken by the hydraulic drill. This method was used in order to supply a data base for correlation. Where excavation and/or drilling was not done, seismographing was done on sites where a fair amount of archaeological information on subsurface structures was known. A transect for a course on a particular site was somewhat arbitrarily chosen.

Using the instruction manual for the Terra-Scout model R-150 as a guide, the spacing of the hammer blows was set at intervals of 10 feet. The course was usually run for 100 feet, but where it seemed necessary to obtain continuous information over a long distance, the course was run to 180 feet – the length of the hammer wire.

In dealing with homogeneous layers, the course length is usually determined by the depth required. The depth tested is about 1/4 times the course length. A high velocity material near the surface would normally decrease the required length because one would only need enough points to show the slope of this high velocity material. However, when the intent is to follow a subsurface structure, the length of the course will necessarily be arbitrary, because the length of the structure is unknown.

In normal homogeneous layers, a reversed course is run to check for sloping subsurface layers, and to get an accurate depth if there are sloping layers. A reverse course is run by moving the geophone to the last hammering point of the forward course and the course is run back toward the point where the first course geophone was placed. Each course by itself gives only an apparent velocity. By averaging the reversed course with the forward course, the true velocity is determined.

However, this was not clearly understood by the operators, and a reversed course was run where the hammering was done in a reversed direction, but without moving the geophone. This simply checks the consistency of the operator without adding new information.

Once the reading on the oscilloscope begins, the size of the wave must be adjusted. This is done with the GAIN control and must be adjusted when the hammering begins at each new distance from the geophone. The first wave to reach the geophone is the important one for timing purposes. Often near the critical distance there is a change in the wave shape and a decrease in wave amplitude. The GAIN control must be increased enough to recognize the smaller wave and to use it for timing.

A marker is used as a reference point in the determination of the time delay between the hammer blow and the wave arrival at the geophone. This marker is placed on the bottom of the first wave at each blow by turning the DELAY dial clockwise while hammering until it is in the bottom of the first wave. From this, the time is read off of the DELAY dial and recorded.

VI. Method of Analysis

All readings were converted into milliseconds. A computer program was then developed to plot a time-distance graph, with distance on the horizontal axis and time on the vertical axis. The scale of this graph varied, depending on the length of the course and the range of millisecond readings.

All possible archaeological cases for that area were hypothesized, and graphs of those cases were drawn.

The points on the time-distance graphs were connected, keeping in mind at all times the slope of the ground surface under the transect. Interpretations were made, based in a large part on knowledge of the sites, such as excavation data, core samples from drill borings, reconstruction drawings, and general knowledge of the most likely structures to occur.

The critical distances - where the layers change - were determined, and the velocities of each layer calculated. Equations for depth calculations, height of walls, and width of depressions were developed, and actual values calculated. The depth equation only applies as long as the velocity of each successive layer increases. Correlations were attempted where possible with excavation data and drawings. Last of all, a profile was drawn of the interpretation of each case.

VII. Data

Lists of Seismograph Readings

Site - Rio Guanajuato, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	36	18.0	100 ft.	263	131.5
20 ft.	102	51.0	90 ft.	244	122.0
30 ft.	110	55.0	80 ft.	222	111.0
40 ft.	142	71.0	70 ft.	200	100.0
50 ft.	170	85.0	60 ft.	181	90.5
60 ft.	183	91.5	50 ft.	170	85.0
70 ft.	203	101.5	40 ft.	144	72.0
80 ft.	225	112.5	30 ft.	120	60.0
90 ft.	243	121.5	20 ft.	101	50.5
100 ft.	268	134.0	10 ft.	32	16.0

Site - Rio Guanajuato, Course 2, Range 0-500 Reverse Course

	Seismographs readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	125	62.5	100 ft.	387	193.5
20 ft.	170	85.0	90 ft.	380	190.0
30 ft.	272	136.0	80 ft.	357	178.5
40 ft.	308	154.0	70 ft.	333	166.5
50 ft.	333	166.5	60 ft.	340	170.0
60 ft.	342	171.0	50 ft.	325	162.5
70 ft.	333	166.5	40 ft.	310	155.0
80 ft.	351	175.5	30 ft.	268	134.0
90 ft.	378	189.0	20 ft.	150	75.0
100 ft.	391	195.5	10 ft.	128	64.0

Site - Rio Guanajuato, Course 3, Range 0-500 Reverse Course

	Seismogrphs readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	40	20.0	100 ft.	500	250.0
20 ft.	89	44.5	90 ft.	456	228.0
30 ft.	109	54.5	80 ft.	375	187.5
40 ft.	148	74.0	70 ft.	348	174.0
50 ft.	202	101.0	60 ft.	308	154.0
60 ft.	276	138.0	50 ft.	201	100.5
70 ft.	345	172.5	40 ft.	144	72.0
80 ft.	374	187.0	30 ft.	103	51.5
90 ft.	452	226.0	20 ft.	90	45.0
100 ft.	502	251.0	10 ft.	53	26.5

Site - Rio Guanajuato, Course 4, Range 0-500 — Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	37	18.5	170 ft.	241	120.5
20 ft.	61	30.5	160 ft.	235	117.5
30 ft.	80	40.0	150 ft.	233	116.5
40 ft.	96	48.0	140 ft.	215	107.5
50 ft.	114	57.0	130 ft.	209	104.5
60 ft.	133	66.5	120 ft.	207	103.5
70 ft.	147	73.5	110 ft.	199	99.5
80 ft.	154	77.0	100 ft.	188	94.0
90 ft.	167	83.5	90 ft.	169	84.5
100 ft.	192	96.0	80 ft.	154	77.0
110 ft.	196	98.0	70 ft.	146	73.0
120 ft.	210	105.0	60 ft.	134	67.0
130 ft.	211	105.5	50 ft.	113	56.5
140 ft.	216	108.0	40 ft.	93	41.5
150 ft.	233	116.5	30 ft.	78	39.0
160 ft.	244	122.0	20 ft.	63	31.5
170 ft.	247	123.5	10 ft.	36	18.0

Site - Cañada de Alfaro, Course 1
Site 43, Range 0-100 — Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	167	16.7	100 ft.	423	42.3
20 ft.	308	30.8	90 ft.	419	41.9
30 ft.	340	34.0	80 ft.	412	41.2
40 ft.	359	35.9			
50 ft.	391	39.1	60 ft.	405.5	40.6
60 ft.	409	40.9	50 ft.	389	38.9
70 ft.	412	41.2	40 ft.	364	36.4
80 ft.	413.5	41.4	30 ft.	343	34.3
90 ft.	418	41.8	20 ft.	307	30.7
100 ft.	418.5	41.9	10 ft.	164	16.4

Cañada de Alfaro, Site 43, Course 2, Range 0-100 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
			0-500 Range		
10 ft.	170	17.0	100 ft.	185	92.5
20 ft.	225.5	22.6	90 ft.	181	90.5
30 ft.	340.5	34.1	80 ft.	179.5	89.5
40 ft.	386.5	38.6	70 ft.	181	90.5
50 ft.	400	40.0	60 ft.	165.5	82.5
60 ft.	421	42.1	0-100 Range		
70 ft.	430	43.0	50 ft.	389	38.9
0-500 Range			40 ft.	382	38.2
80 ft.	180	90.0	30 ft.	337	33.7
90 ft.	187	93.5	20 ft.	330	33.0
100 ft.	185.5	92.5	10 ft.	319	31.9

Cañada de Alfaro, Site 43, Course 3, Range 0-100 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	89	8.9	100 ft.	386	38.6
20 ft.	181	18.1	90 ft.	343	34.3
30 ft.	267	26.7	80 ft.	332	33.2
40 ft.	294	29.4	70 ft.	326	32.6
50 ft.	306	30.6	60 ft.	315	31.5
60 ft.	314	31.4	50 ft.	308	30.8
70 ft.	325	32.5	40 ft.	293	29.3
80 ft.	331	33.1	30 ft.	267	26.7
90 ft.	342	34.2	20 ft.	180	18.0
100 ft.	386	38.6	10 ft.	88	8.0

Cañada de Alfaro, Site 22, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10ft.	18	9.0	180 ft.	128	64.0
20 ft.	36	18.0	170 ft.	128	64.0
30 ft.	56	28.0	160 ft.	122	61.0
40 ft.	67	33.5	150 ft.	117	58.5
50 ft.	77	38.5	140 ft.	110	55.0
60 ft.	80	40.0	130 ft.	106	53.0
70 ft.	82	41.0	120 ft.	104	52.0
80 ft.	86	43.0	110 ft.	102	51.0
90 ft.	91	45.5	100 ft.	90	45.0
100 ft.	91	45.5	90 ft.	90	45.0
110 ft.	102	51.0	80 ft.	84	42.0
120 ft.	104	52.0	70 ft.	82	41.0
130 ft.	107	53.5	60 ft.	79	39.5
140 ft.	111	55.5	50 ft.	77	33.5
150 ft.	118	59.0	40 ft.	68	34.0
160 ft.	122	61.0	30 ft.	54	27.0
170 ft.	130	65.0	20 ft.	37	18.5
180 ft.	128	64.0	10 ft.	29	14.5

Cañada de Alfaro, Site 22, Course 2, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	18	90.0	130 ft.	244	122.0
20 ft.	37	18.5	120 ft.	229	114.5
30 ft.	53	26.5	110 ft.	218	109.0
40 ft.	69	34.5	100 ft.	180	90.0
50 ft.	94	47.0	90 ft.	168	84.0
60 ft.	110	55.0	80 ft.	143	71.5
70 ft.	132	66.0	70 ft.	132	66.0
80 ft.	145	72.5	60 ft.	111	55.5
90 ft.	152	76.0	50 ft.	94	47.0
100 ft.	177	88.5	40 ft.	67	33.5
110 ft.	216	108.0	30 ft.	65	32.5
120 ft.	229	114.5	20 ft.	37	18.5
130 ft.	244	122.0	10 ft.	18	9.0

Cañada de Alfaro, Site 22, Course 3, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	15	.75	180 ft.	214	107.0
20 ft.	36	18.0	170 ft.	192	96.0
30 ft.	53	26.5	160 ft.	185	92.5
40 ft.	69	34.5	150 ft.	177	88.5
50 ft.	73	36.5	140 ft.	159	79.5
60 ft.	81	40.5	130 ft.	155	77.5
70 ft.	88	44.0	120 ft.	133	66.5
80 ft.	95	47.5	110 ft.	124	62.0
90 ft.	101	50.5	100 ft.	104	52.0
100 ft.			90 ft.	99	49.5
110 ft.	127	63.5	80 ft.	92	46.0
120 ft.	135	67.5	70 ft.	83	41.5
130 ft.	157	78.5	60 ft.	77	38.5
140 ft.	162	81.0	50 ft.	69	34.5
150 ft.	176	83.0	40 ft.	64	32.0
160 ft.	186	93.0	30 ft.	60	30.0
170 ft.	191	95.5	20 ft.	31	15.5
180 ft.	214	107.0	10 ft.	15	7.5

Cañada de Alfaro, Site 22, Course 4, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	16	8.0	100 ft.	106	53.0
20 ft.	48	24.0	90 ft.	104	52.0
30 ft.	58	29.0	80 ft.	98	49.0
40 ft.	65	32.5	70 ft.	89	44.5
50 ft.	75	37.5	60 ft.	85	42.5
60 ft.	83	41.5	50 ft.	76	38.0
70 ft.	89	44.5	40 ft.	67	33.5
80 ft.	96	48.0	30 ft.	59	28.5
90 ft.	104	52.0	20 ft.	43	21.5
100 ft.	106	53.0	10 ft.	16	8.0

Cañada de Alfaro, Site 11, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	14	7.0	100 ft.	97	48.5
20 ft.	27	13.5	90 ft.	91	45.5
30 ft.	36	18.0	80 ft.	93	46.5
40 ft.	45	22.5	70 ft.	88	44.0
50 ft.	50	25.0	60 ft.	55	27.5
60 ft.	56	28.0	50 ft.	50	25.0
70 ft.	87	43.5	40 ft.	45	22.5
80 ft.	94	47.0	30 ft.	37	18.5
90 ft.	92	46.0	20 ft.	28	14.0
100 ft.	98	49.0	10 ft.	14	7.0

Cañada de Alfaro, Site 11, Course 2, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	14	7.0	100 ft.	70	35.0
20 ft.	30	15.0	90 ft.	66	33.0
30 ft.	40	20.0	80 ft.	63	31.5
40 ft.	45	22.5	70 ft.	60	30.0
50 ft.	53	26.5	60 ft.	55	27.5
60 ft.	57	28.5	50 ft.	52	26.0
70 ft.	61	30.5	40 ft.	45	22.5
80 ft.	65	32.5	30 ft.	39	19.5
90 ft.	67	33.5	20 ft.	31	15.5
100 ft.	71	35.5	10 ft.	18	9.0

Cañada de Alfaro, Site 10, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	7	3.5	100 ft.	75	37.5
20 ft.	24	12.0	90 ft.	73	36.5
30 ft.	47	23.5	80 ft.	71	35.5
40 ft.	60	30.0	70 ft.	70	35.0
50 ft.	68	34.0	60 ft.	69	34.5
60 ft.	69	34.5	50 ft.	68	34.0
70 ft.	70	35.0	40 ft.	60	30.0
80 ft.	71	35.5	30 ft.	47	23.5
90 ft.	72	36.0	20 ft.	24	12.0
100 ft.	74	37.0	10 ft.	4	2.0

Cañada de Alfaro, Site 10, Course 2, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	2	1.0	100 ft.	72	36.0
20 ft.	26	13.0	90 ft.	71	35.5
30 ft.	51	25.5	80 ft.	70	35.0
40 ft.	60	30.0	70 ft.	66	33.0
50 ft.	63	31.5	60 ft.	66	33.0
60 ft.	66	33.0	50 ft.	63	31.5
70 ft.	67	33.5	40 ft.	60	30.0
80 ft.	71	35.5	30 ft.	51	25.5
90 ft.	71	35.5	20 ft.	27	13.5
100 ft.	72	36.0	10 ft.	2	1.0

Cañada de Alfaro, Site 57, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	8	4.0	100 ft.	73	36.5
20 ft.	21	10.5	90 ft.	73	36.5
30 ft.	42	21.0	80 ft.	69	34.5
40 ft.	56	28.5	70 ft.	64	32.0
50 ft.	61	30.5	60 ft.	63	31.5
60 ft.	63	31.5	50 ft.	61	30.5
70 ft.	64	32.0	40 ft.	55	27.5
80 ft.	70	35.0	30 ft.	43	21.5
90 ft.	73	36.5	20 ft.	26	13.0
100 ft.	73	36.5	10 ft.	6	3.0

Cañada de Alfaro, Site 57, Course 2, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	7	3.5	100 ft.	70	35.0
20 ft.	24	12.0	90 ft.	70	35.0
30 ft.	43	21.5	80 ft.	71	35.5
40 ft.	59	29.5	70 ft.	74	37.0
50 ft.	62	31.0	60 ft.	69	34.5
60 ft.	68	34.0	50 ft.	63	31.5
70 ft.	74	37.0	40 ft.	59	29.5
80 ft.	72	36.0	30 ft.	43	21.5
90 ft.	71	35.5	20 ft.	21	10.5
100 ft.	70	35.0	10 ft.	7	3.5

Cañada de Alfaro, Site 61, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	8	4.0	100 ft.	80	40.0
20 ft.	25	12.5	90 ft.	75	37.5
30 ft.	43	21.5	80 ft.	69	34.5
40 ft.	54	27.0	70 ft.	64	32.0
50 ft.	58	29.0	60 ft.	60	30.0
60 ft.	61	30.5	50 ft.	56	28.0
70 ft.	64	32.0	40 ft.	52	26.0
80 ft.	70	35.0	30 ft.	43	21.5
90 ft.	76	38.0	20 ft.	20	10.0
100 ft.	80	40.0	10 ft.	4	2.0

Cañada de Alfaro, Site 61, Course 2, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	2	1.0	100 ft.	73	36.5
20 ft.	29	14.5	90 ft.	68	34.0
30 ft.	41	20.5	80 ft.	62	31.0
40 ft.	48	24.0	70 ft.	58	29.0
50 ft.	50	25.0	60 ft.	53	26.5
60 ft.	54	27.0	50 ft.	49	24.5
70 ft.	58	29.0	40 ft.	47	23.5
80 ft.	63	31.5	30 ft.	40	20.0
90 ft.	68	34.0	20 ft.	30	15.0
100 ft.	73	36.5	10 ft.	2	1.0

Site - Leon - Silao, Course 1, Range 0-500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	5	2.5	100 ft.	138	69.0
20 ft.	23	11.5	90 ft.	136	68.0
30 ft.	37	18.5	80 ft.	121	60.5
40 ft.	47	23.5	70 ft.	115	57.5
50 ft.	66	33.0	60 ft.	97	48.5
60 ft.	95	47.5	50 ft.	66	33.0
70 ft.	No reading		40 ft.	46	23.0
80 ft.	121	60.5	30 ft.	40	20.0
90 ft.	135	67.5	20 ft.	23	11.5
100 ft.	140	70.0	10 ft.	5	2.5

Site - Leon - Silao, Course 2, Range 0 - 500 Reverse Course

	Seismograph readings	Milliseconds		Seismograph readings	Milliseconds
10 ft.	5	2.5	100 ft.	70	35.0
20 ft.	25	12.5	90 ft.	66	33.0
30 ft.	38	19.0	80 ft.	59	29.5
40 ft.	42	21.0	70 ft.	54	27.0
50 ft.	45	22.5	60 ft.	50	25.0
60 ft.	50	25.0	50 ft.	46	23.0
70 ft.	54	27.0	40 ft.	41	20.5
80 ft.	59	29.5	30 ft.	38	19.0
90 ft.	65	32.5	20 ft.	25	12.5
100 ft.	71	35.5	10 ft.	5	2.5

Formulae

1. Depth formulae for constant-velocity layers are given below where:

K = constant
n = number of a given layer or strata
V = velocity
d = depth
C = critical distance, or the distance from the geophone to the point at which the slope of a given velocity line changes
t = time
g = width of a depression
h = height of a wall

$$K_n = \frac{1}{2}\sqrt{\frac{V_{n+1} - V_n}{V_{n+1} + V_n}}$$

$$d_n = C_n K_n + d_{n-1} + \sum_{i=0}^{n-2} (d_{i+1} - d_i) \left[\frac{V_{n+1}}{V_{i+1}} \sqrt{\frac{V_n^2 - V_{i+1}^2}{V_{n+1}^2 - V_n^2}} - \right.$$

$$\frac{V_n}{V_{i+1}} \sqrt{\frac{V_{n+1}^2 - V_{i+1}^2}{\sqrt{V_{n+1}^2 - V_n^2}}}$$

where $d_o = 0$ by definition

2. Depth formula for sloped ground surface with pyramids:

   Possible only if the angle of the walls are known.

3. Flat ground surface with a platform:

   Again, the solution is possible only if the angle is known or if a true reversed course was run.

4. Height of a wall, as in Case 2.

   h = height of wall

$$h = \frac{d_i\,(V_2^2 - 2V_1^2)}{V_1^2 + V_2^2 - V_1\sqrt{V_2^2 - V_1^2}}$$

   This formula only applies if the velocity of the second stratum is at least $\sqrt{2}$ times the velocity of the first stratum.

5. Width of a depression, as in Cases 4 and 5 in the following section:

$$g = \left(\frac{1}{V_2 - V_1}\right)\left[t_o V_1 V_2 + \frac{2(V_1^2 h - h V_2^2)}{\sqrt{V_2^2 - V_1^2}} - C^1 V_1\right]$$

   C' is any point after which the floor is picked up beyond the depression, at t_o.

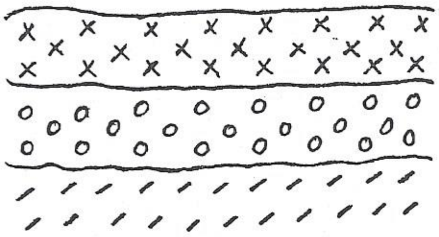
General Operating Principles

1. A straight line indicates that the hammer's path is parallel to the stratum of the quickest path.
2. A curved graph will veer up (away from the straight) if the quickest path is veering away from the hammer path.
3. A curved graph veers down if the quickest path is getting closer progressively to the hammer path.

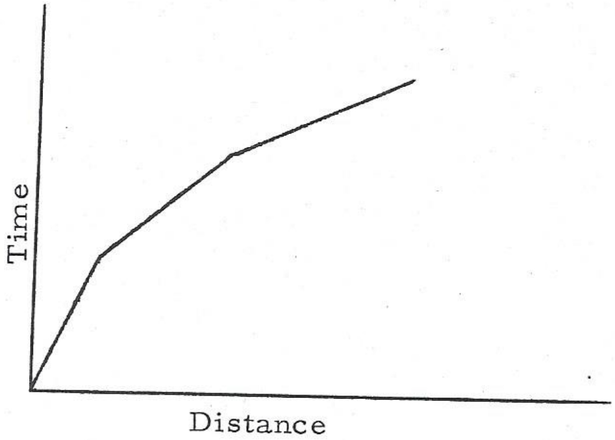
Hypothetical Archeological Cases and Their Time-Distance Graphs

Case 1. A flat ground surface and homogeneous strata parallel to the surface.

Hypothetical Stratigraphy

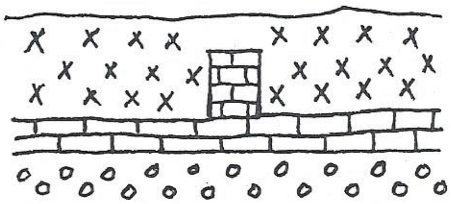


Hypothetical Time-Distance Graph

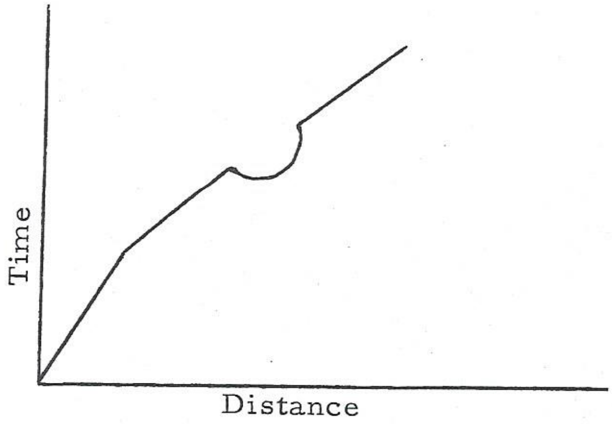


Case 2. A flat ground surface with the strata parallel to the surface, and a wall and floor of stone.

Hypothetical Stratigraphy



Hypothetical Time-Distance Graph



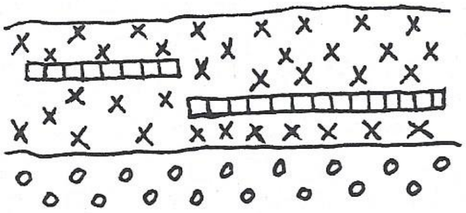
a. For exact numbers, the wall and floor must be about the same density.

b. Otherwise the above graph applies to all cases and the wall occurs between the bounds of the dip.

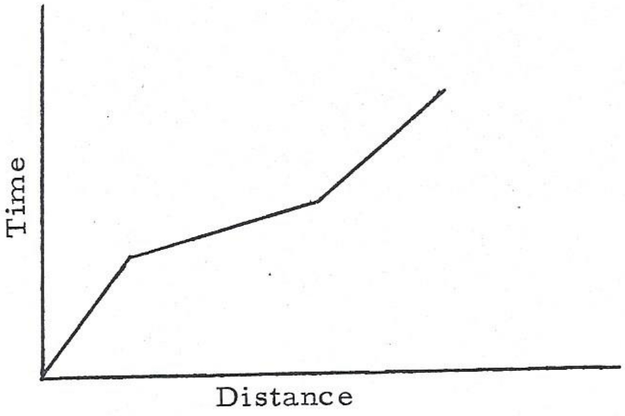
c. The only way to differentiate different materials used for the wall and floor will be in the sharpness of the curve. If the floor is of packed earth and the wall of stone, the curve will approach a straight line.

Case 3. Similar to case 2 above, except that the transect is following a wall which ends, and the path jumps down to pick up a floor which is lower than the wall

Hypothetical Stratigraphy

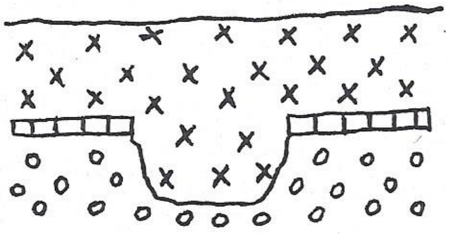


Hypothetical Time-Distance Graph

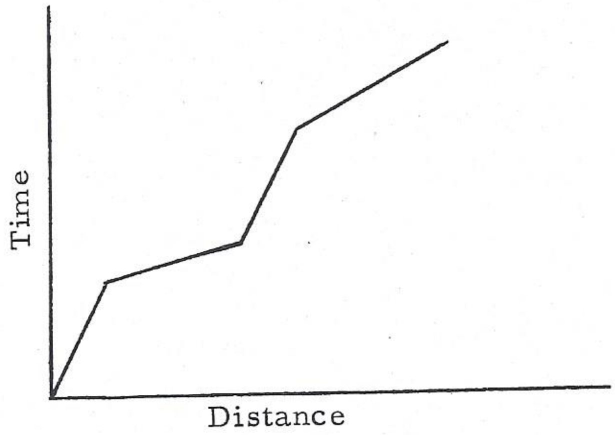


Case 4. A flat ground surface with the strata parallel to the surface. A depression filled with approximately the same material as the first stratum.

Hypothetical Stratigraphy



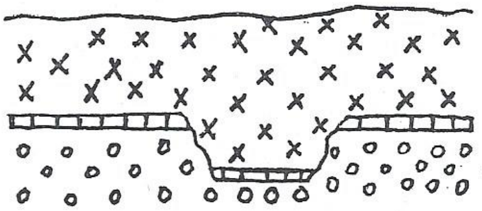
Hypothetical Time-Distance Graph



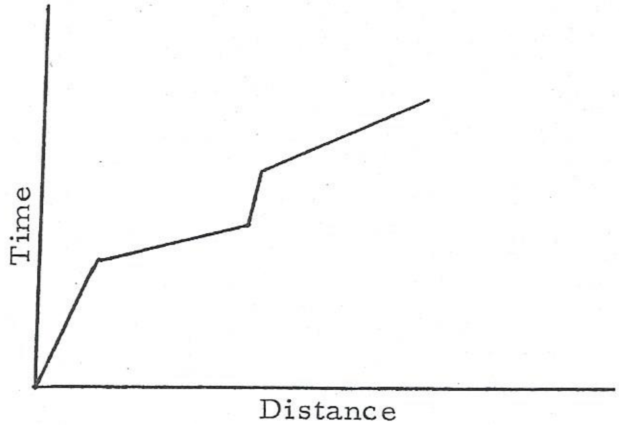
a. A graph of this type will apply to any interruption in the stratum - not necessarily a man-made depression.

Case 5. A flat ground surface with the strata parallel to the surface. A depression filled with a layer of rocks at the bottom.

Hypothetical Stratigraphy



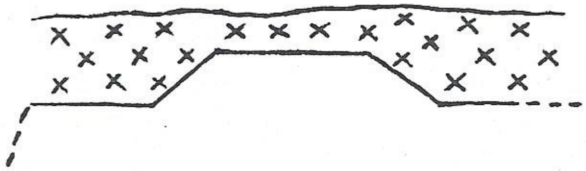
Hypothetical Time-Distance Graph



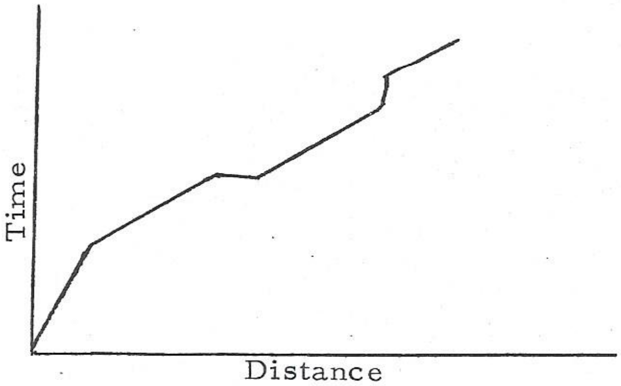
a. This is the same general graph as Case 4 above, but the third slope will be shorter. This case will rarely occur.

Case 6. A flat ground surface, one platform with one pyramid on top.

Hypothetical Stratigraphy



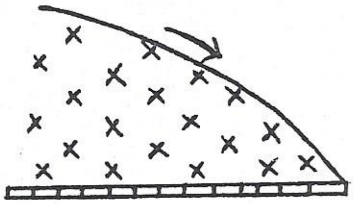
Hypothetical Time-Distance Graph



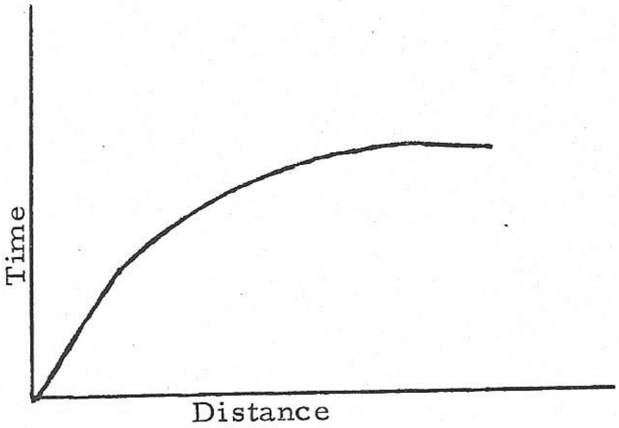
a. A single platform only, or any number of pyramids will give a variation of this graph, with more or less curves.

Case 7. A sloped ground surface, and a floor which is not parallel to the surface. The course runs downhill.

Hypothetical Stratigraphy

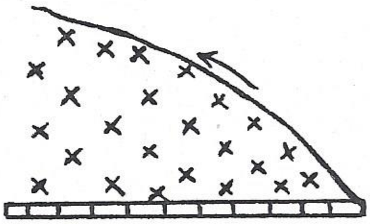


Hypothetical Time-Distance Graph

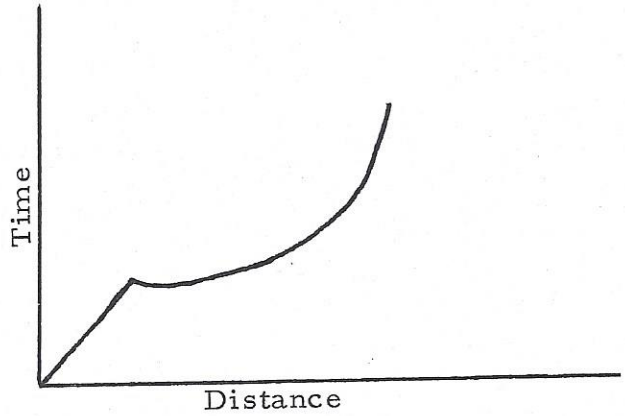


Case 8. A sloped ground surface, and a floor which is not parallel to the surface. The course runs uphill.

Hypothetical Stratigraphy

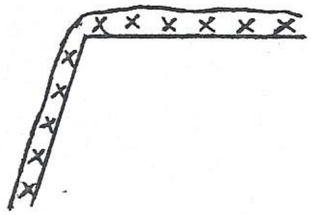


Hypothetical Time-Distance Graph

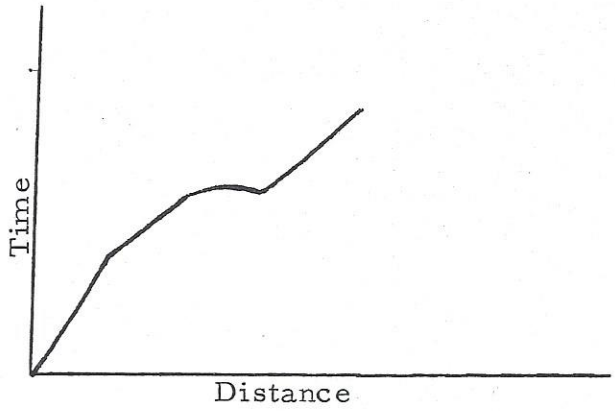


Case 9. A sloped ground surface, 1 single platform. The course begins at the top and runs downhill.

Hypothetical Stratigraphy

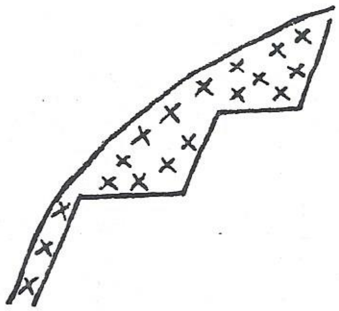


Hypothetical Time-Distance Graph

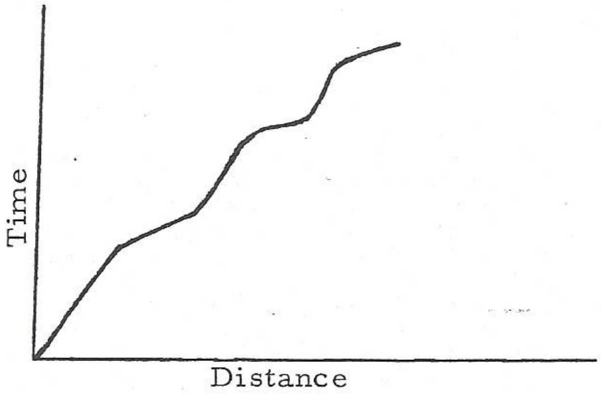


Case 10. A sloped ground surface, and any number of pyramid walls. The course runs uphill.

Hypothetical Stratigraphy



Hypothetical Time-Distance Graph



VIII. Results

List of Critical Distances, Velocities and Depth Values

Site	Site #	Course	Layer of Strata	Critical Distance in feet*	Velocity in ft/sec	Depth in ft.
Rio Guanajuato		1	1	20.0	303.0	7.3
			2		1,013.0	6.2
Rio Guanajuato		3	1	20.0	541.0	
			2		387.0	
Rio Guanajuato		4	1	20.0	741.0	
					1,685.0	
Cañada de Alfaro	43	1	1	20.0	709.0	9.1
					7,207.0	
Cañada de Alfaro	43	3	1	30.0	1,124.0	12.0
			2	50.0	5,128.0	25.5
			3	70.0	10,526.0	31.8
			4	90.0	11,764.0	
			5		2,273.0	
Cañada de Alfaro	22	1	1	30.0	1,053.0	8.1
			2	50.0	1,905.0	23.4
			3	90.0	5,714.0	
					4,865.0	
Cañada de Alfaro	22	Reverse	1	40.0	1,229.0	16.7
					7,000.0	
Cañada de Alfaro	22	2	1	50.0	1,052.0	2.1
					1,067.0	
Cañada de Alfaro	22	Reverse	1	30.0	852.0	
			2	40.0	100.0	
			3	60.0	909.0	
			4	80.0	1,250.0	
			5		436.0	
Cañada de Alfaro	22	3	1	40.0	1,111.0	
			2	50.0	5,000.0	
			3	60.0	2,500.0	
			4	100.0	2,911.0	
			5	130.0	1,224.0	
			6		1,755.0	
Cañada de Alfaro	22	Reverse	1	20.0	1,250.0	
			2	30.0	690.0	
			3	80.0	3,125.0	
			4		1,818.0	
Cañada de Alfaro	22	4	1	20.0	625.0	7.5
			2	50.0	2,222.0	17.7
			3		3,290.0	
Cañada de Alfaro	22	Reverse	1	20.0	741.0	6.2
			2	40.0	1,666.0	12.8
			3	60.0	2,222.0	24.7
			4		3,810.0	

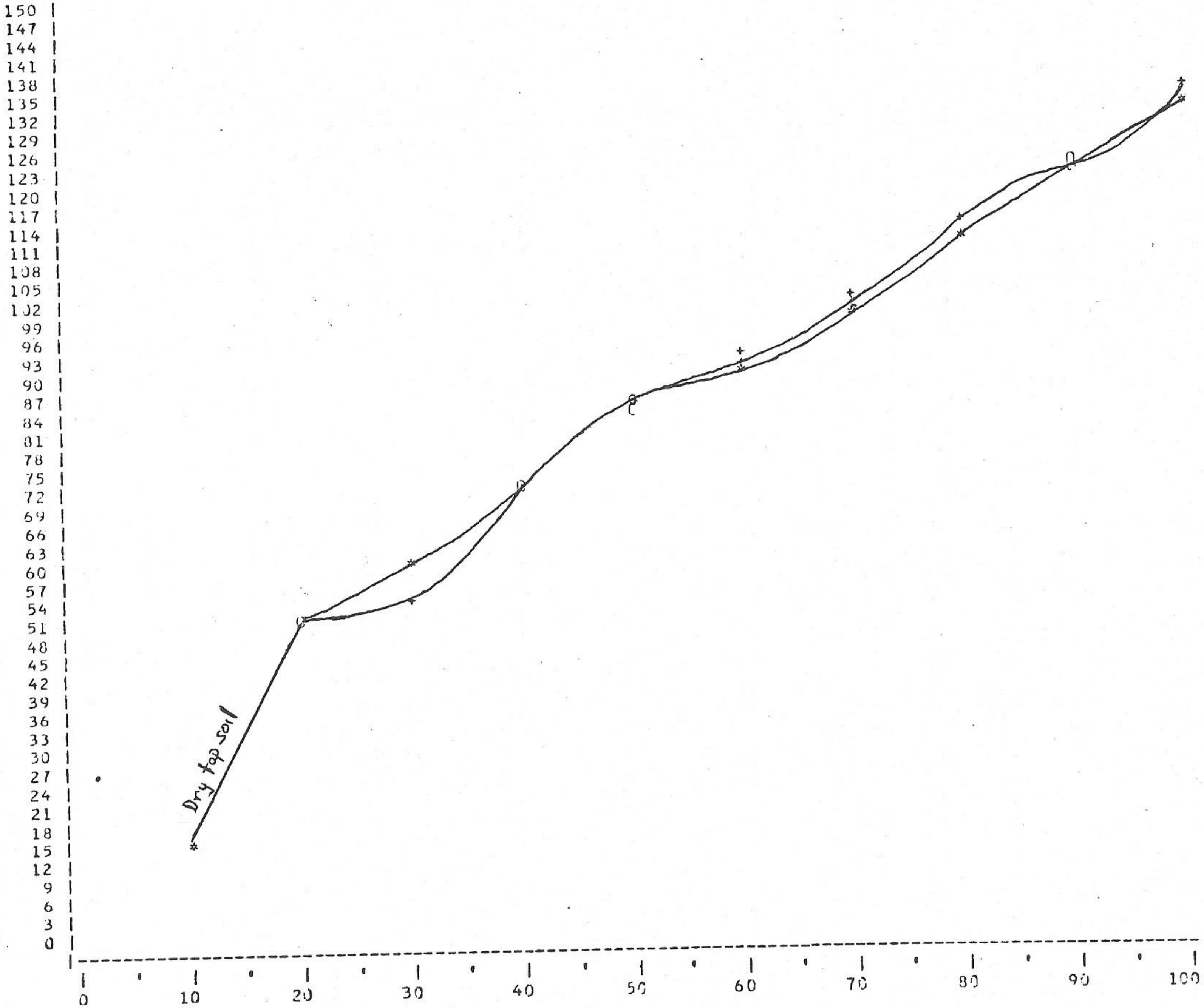
---

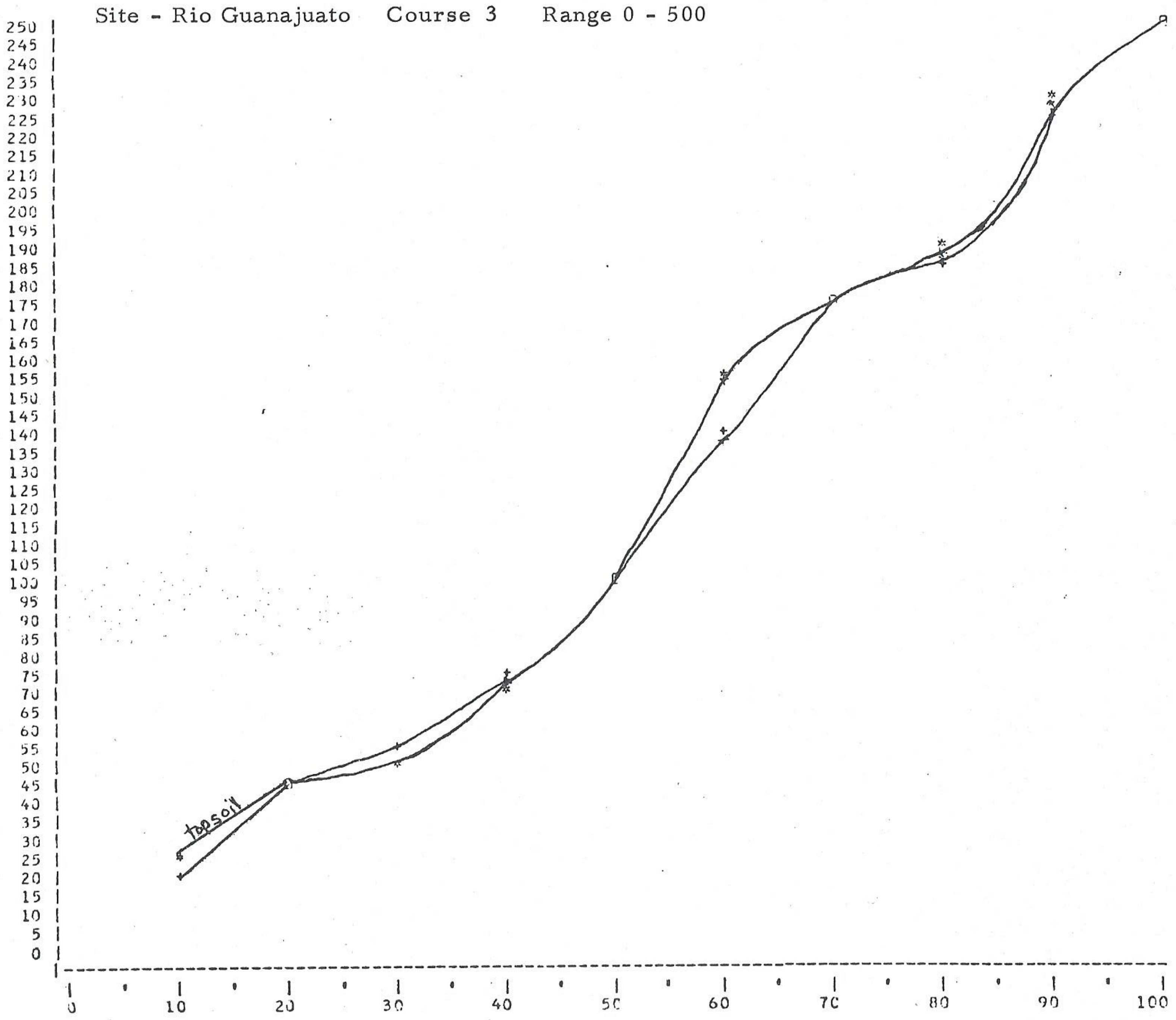
* The critical distance is the distance from the geophone to the point at which the slope of a given velocity line changes.

Site	Site #	Course	Layer of Strata	Critical Distance in feet	Velocity in ft/sec	Depth in ft.
Cañada de Alfaro	11	1	1	20.0	1,538.0	4.3
			2	40.0	2,222.0	12.7
			3	60.0	3,636.0	
			4	70.0	645.0	
			5		5,454.0	
Cañada de Alfaro	11	2	1	20.0	1,250.0	5.9
			2	50.0	2,610.0	18.6
			3	80.0	5,000.0	30.8
			4		6,666.0	
Cañada de Alfaro	11	Reverse	1	20.0	1,538.0	5.8
			2	50.0	2,858.0	18.1
			3	80.0	5,455.0	22.8
			4		5,714.0	
Cañada de Alfaro	10	1	1	20.0	1,176.0	5.5
			2	70.0	2,174.0	32.6
			3		10,500.0	
Cañada de Alfaro	10	2	1	30.0	817.0	12.7
			2	80.0	5,000.0	42.7
			3		20,000.0	
Cañada de Alfaro	10	Reverse	1	30.0	817.0	13.3
			2		6,666.0	
Cañada de Alfaro	57	1	1	40.0	1,224.0	17.0
			2		7,500.0	
Cañada de Alfaro	57	Reverse	1	30.0	1,080.0	6.9
			2	40.0	1,667.0	19.9
			3		6,666.0	
Cañada de Alfaro	57	2	1	40.0	1,154.0	18.0
			2		10,909.0	
Cañada de Alfaro	61	1	1	30.0	1,143.0	7.2
			2	40.0	1,818.0	18.0
					4,615.0	
Cañada de Alfaro	61	Reverse	1	20.0	1,250.0	
			2	30.0	870.0	
			3	40.0	2,222.0	
			4	70.0	5,000.0	
			5		3,750.0	
Cañada de Alfaro	61	2	1	20.0	741.0	6.2
			2	30.0	1,667.0	12.7
			3	40.0	2,857.0	24.8
			4	50.0	10,000.0	
			5	90.0	3,478.0	
			6		4,000.0	
Cañada de Alfaro	61	Reverse	1	20.0	714.0	6.2
			2	40.0	2,353.0	22.0
			3	50.0	10,000.0	
			4	80.0	4,615.0	
			5		3,636.0	
Leon-Silao		1	1	30.0	1,142.0	5.0
			2		1,429.0	
Leon-Silao		2	1	20.0	1,000.0	6.4
			2	40.0	2,352.0	17.1
			3	70.0	5,000.0	
			4		3,535.0	

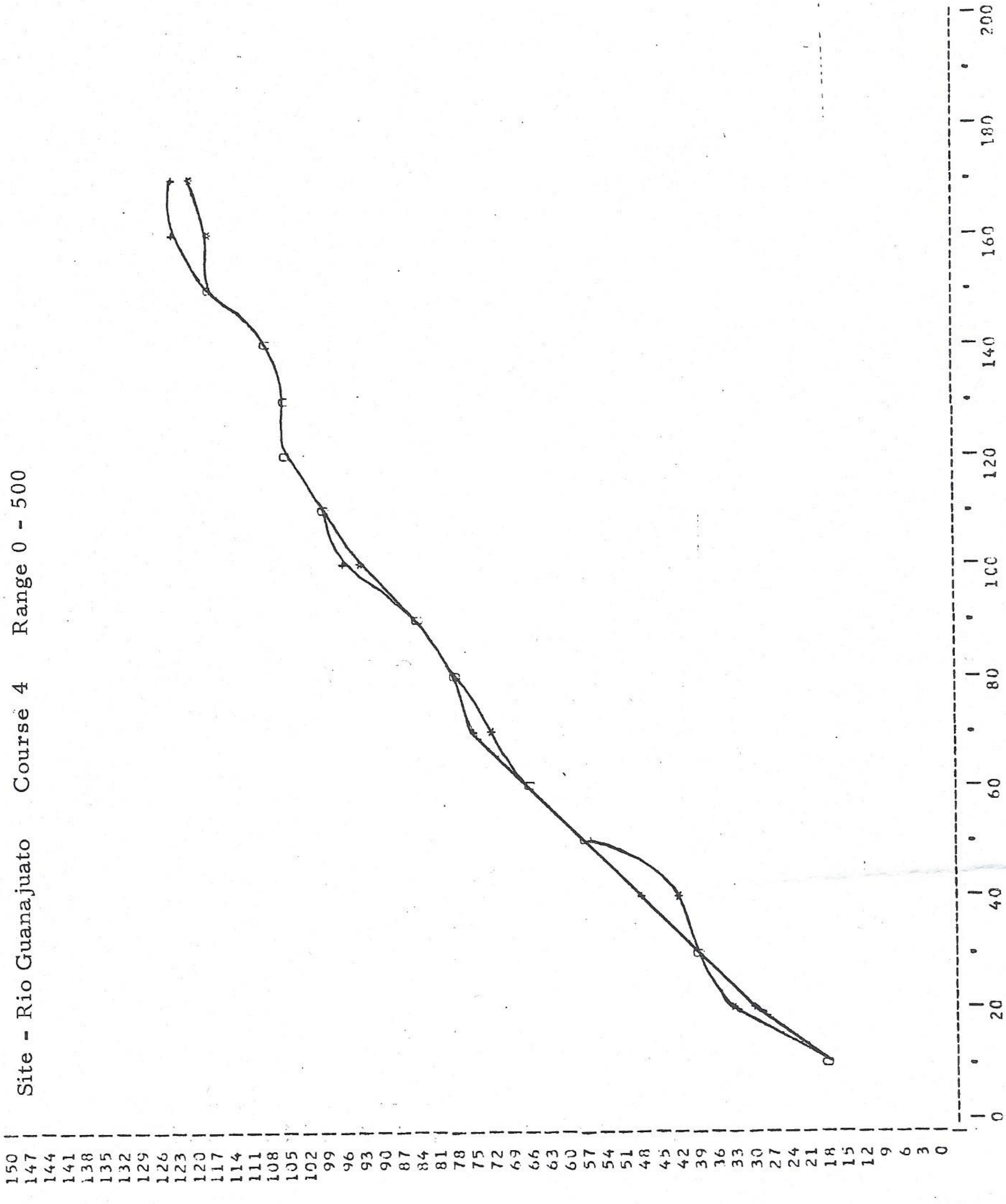
Site - Rio Guanajuato Course 1 Range 0 - 500

ACTUAL TIME - DISTANCE GRAPHS

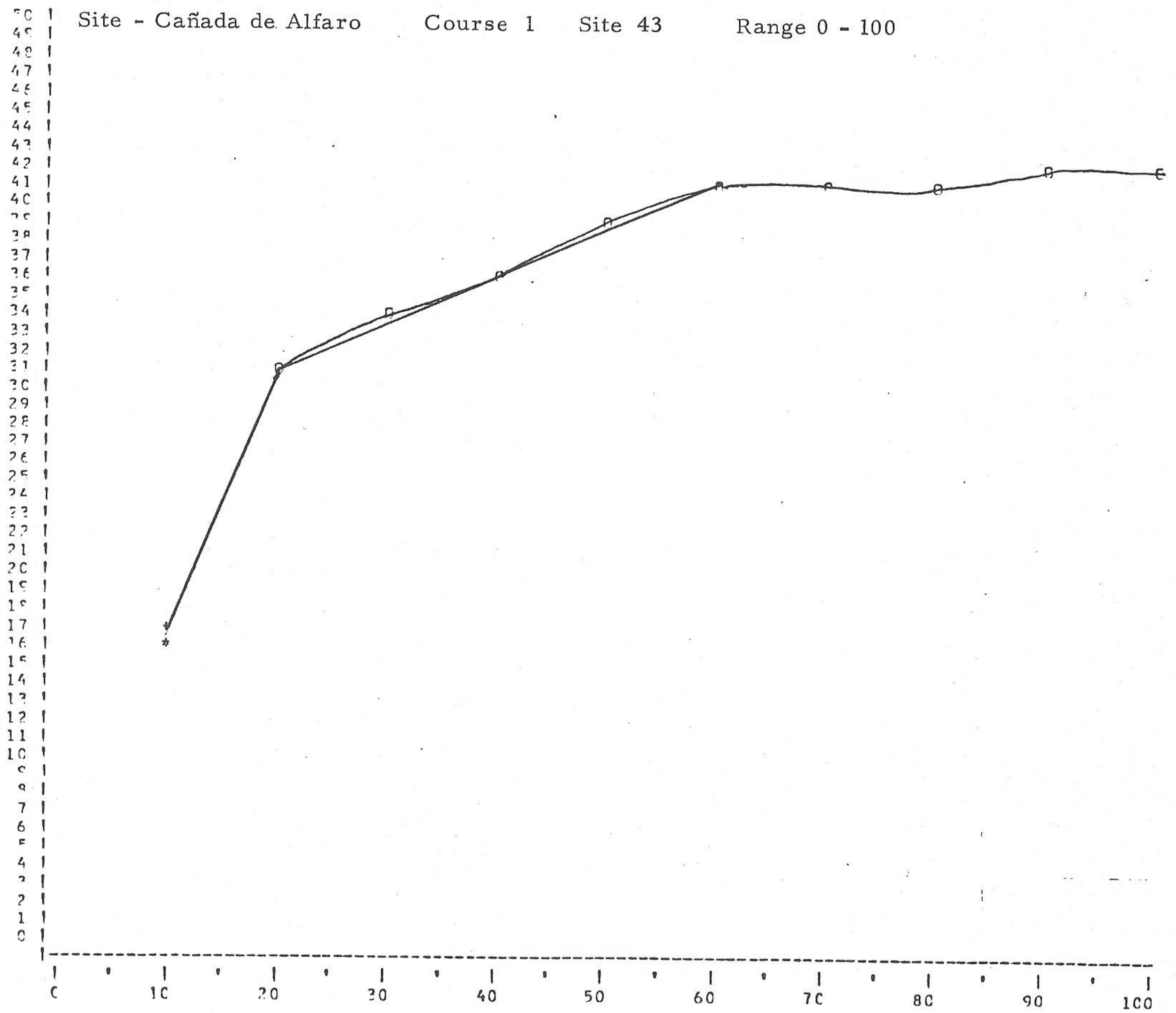




Site - Rio Guanajuato   Course 3   Range 0 - 500

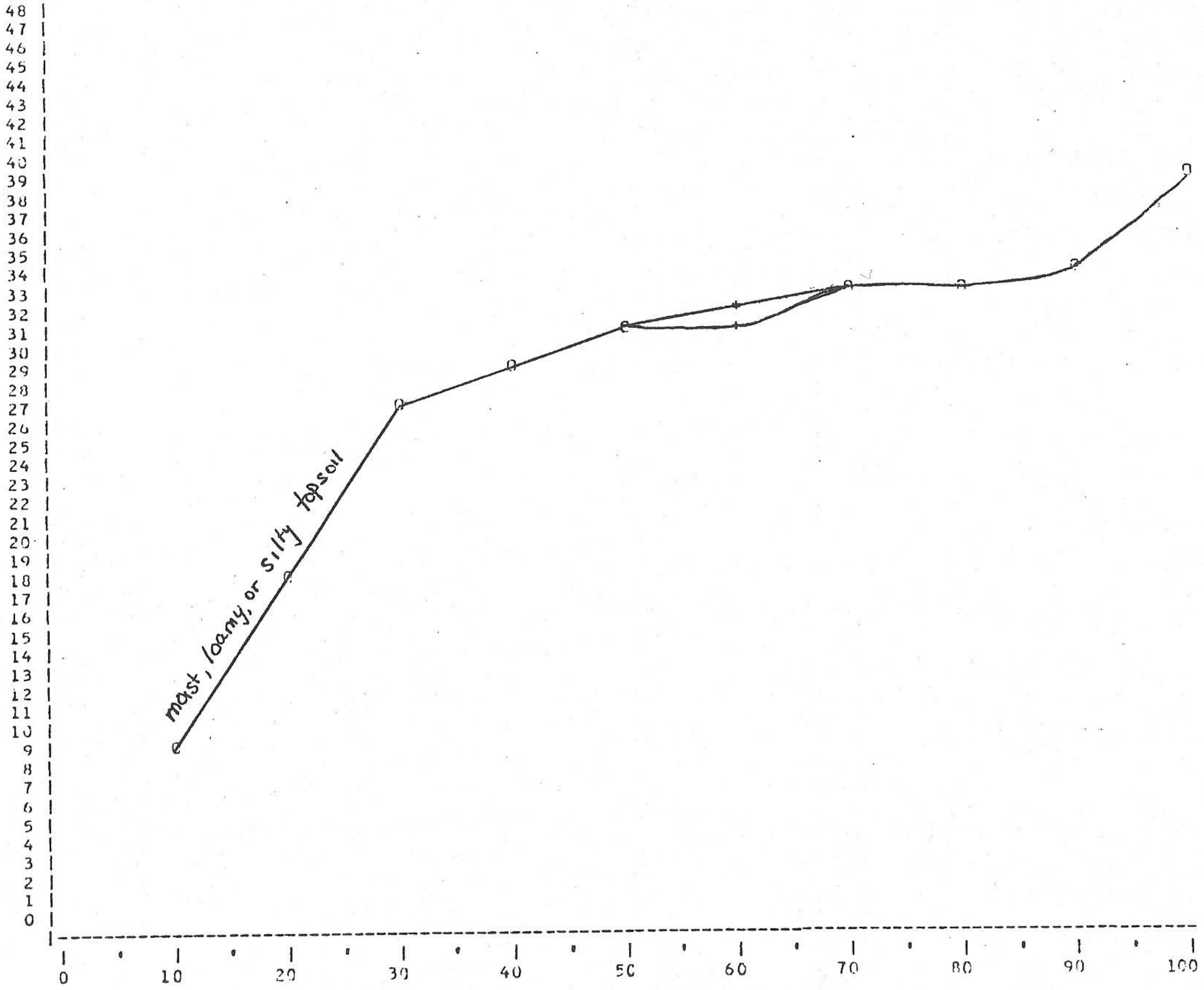


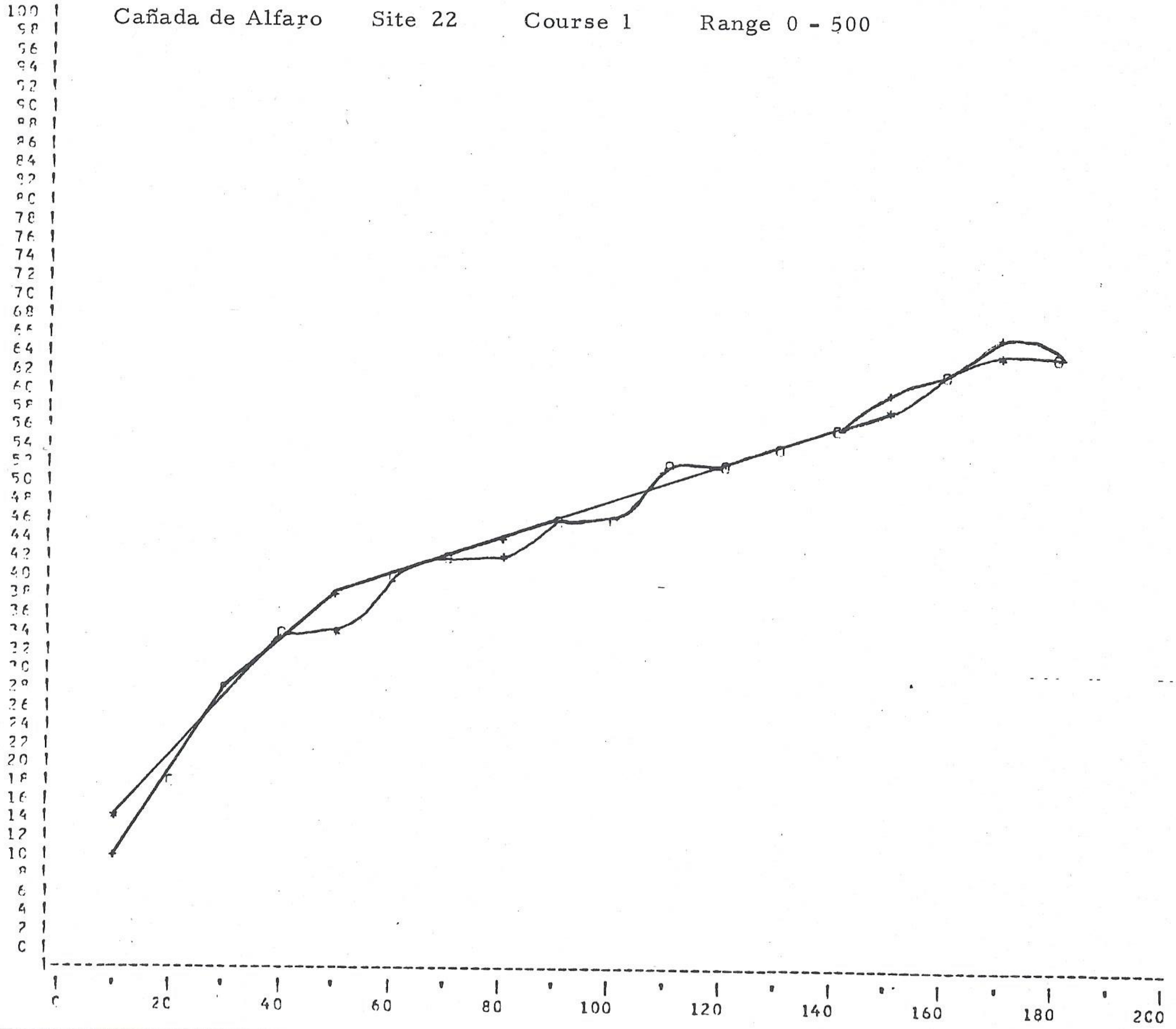
Site - Rio Guanajuato   Course 4   Range 0 - 500



Site - Cañada de Alfaro Course 1 Site 43 Range 0 - 100

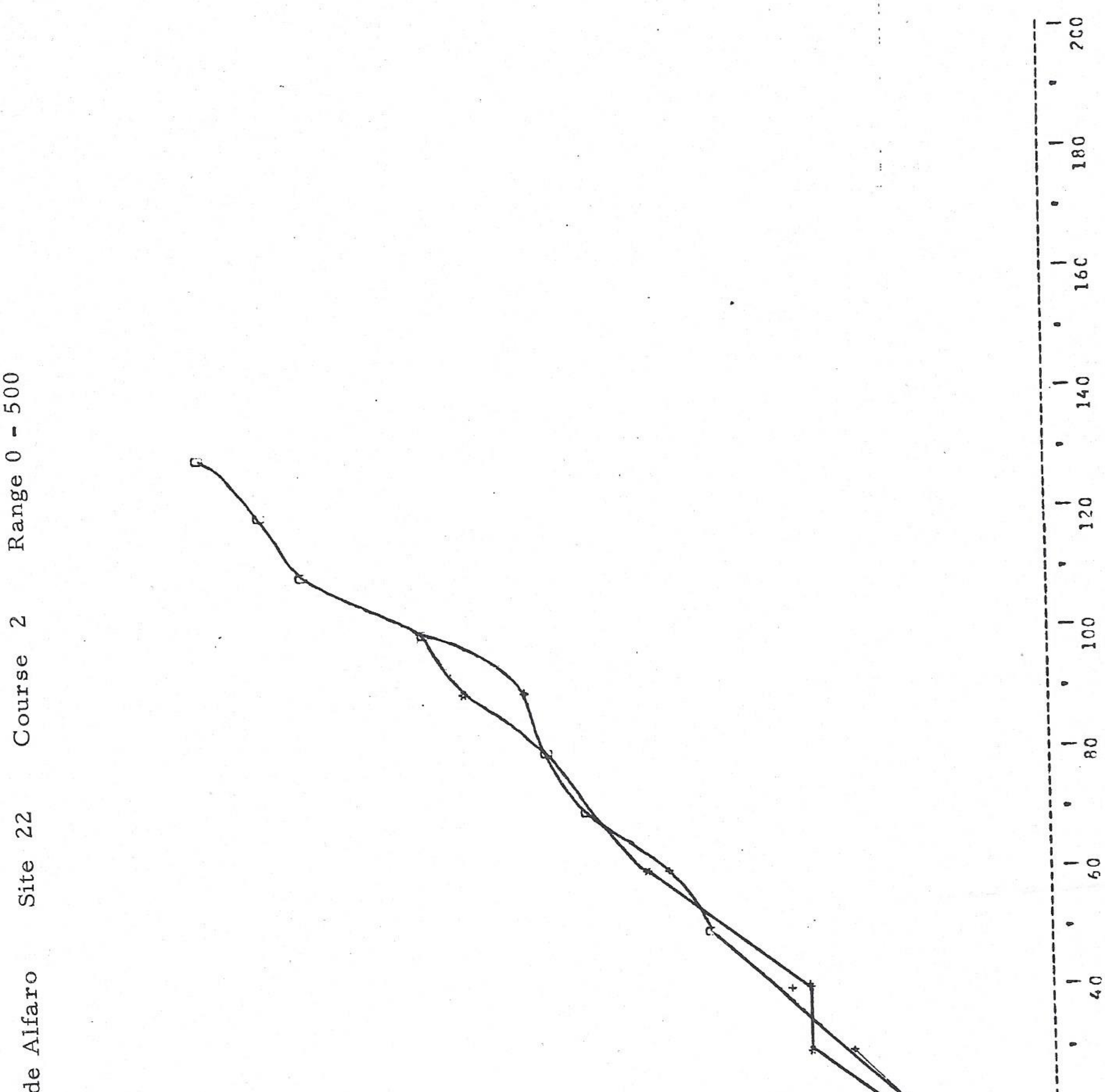
Cañada de Alfaro Site 43 Course 3 Range 0 - 100



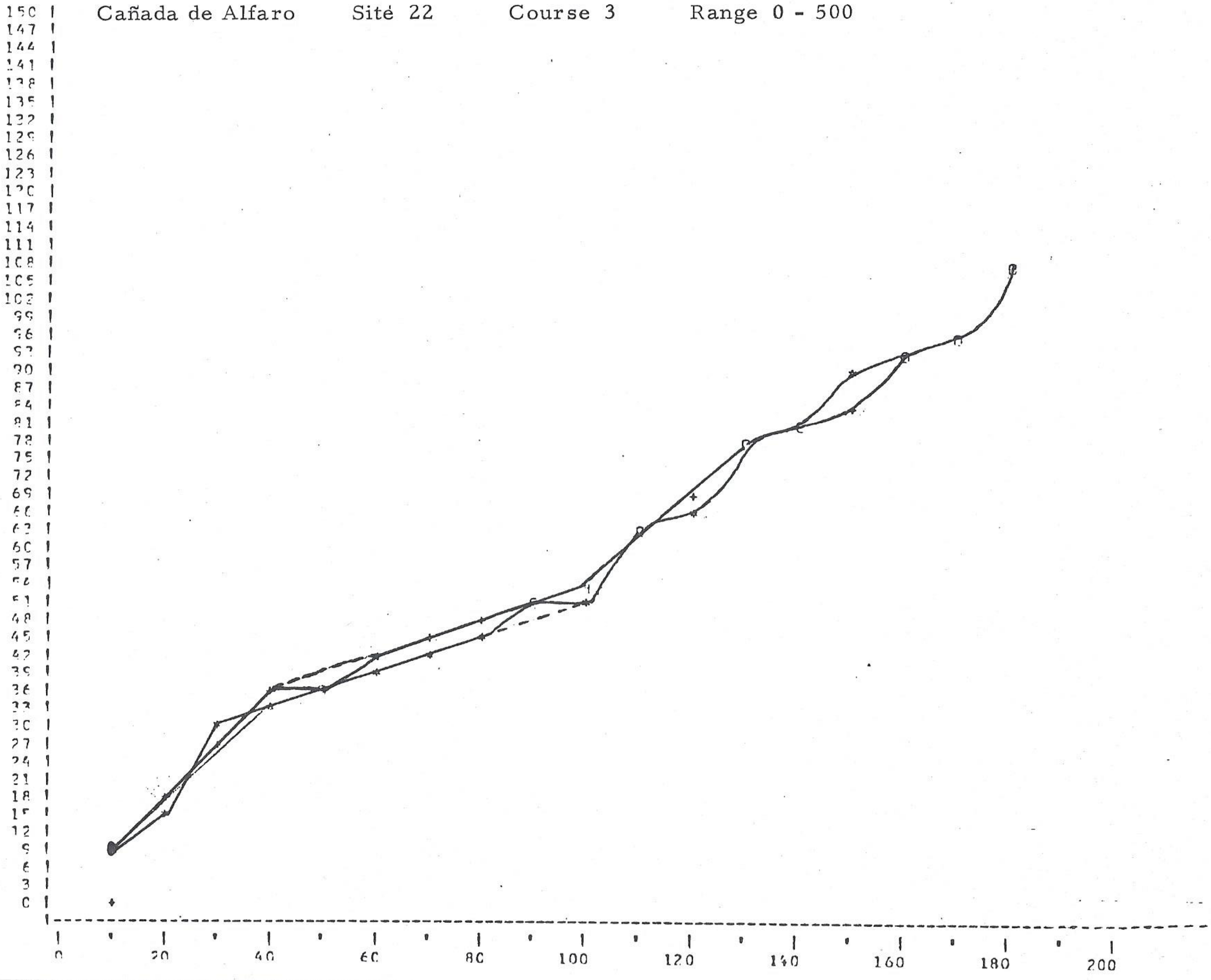


Cañada de Alfaro Site 22 Course 1 Range 0 - 500

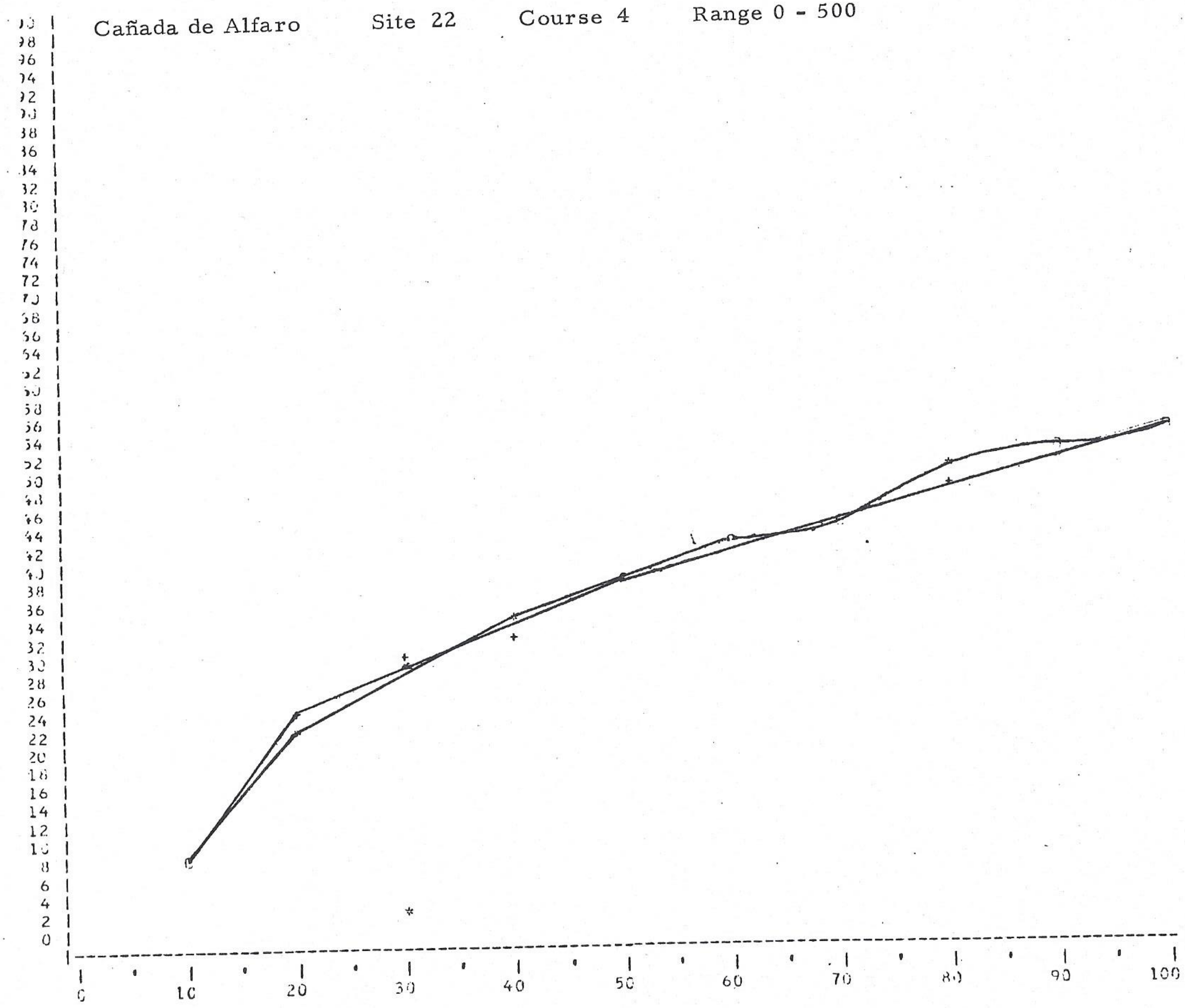
Cañada de Alfaro Site 22 Course 2 Range 0 - 500

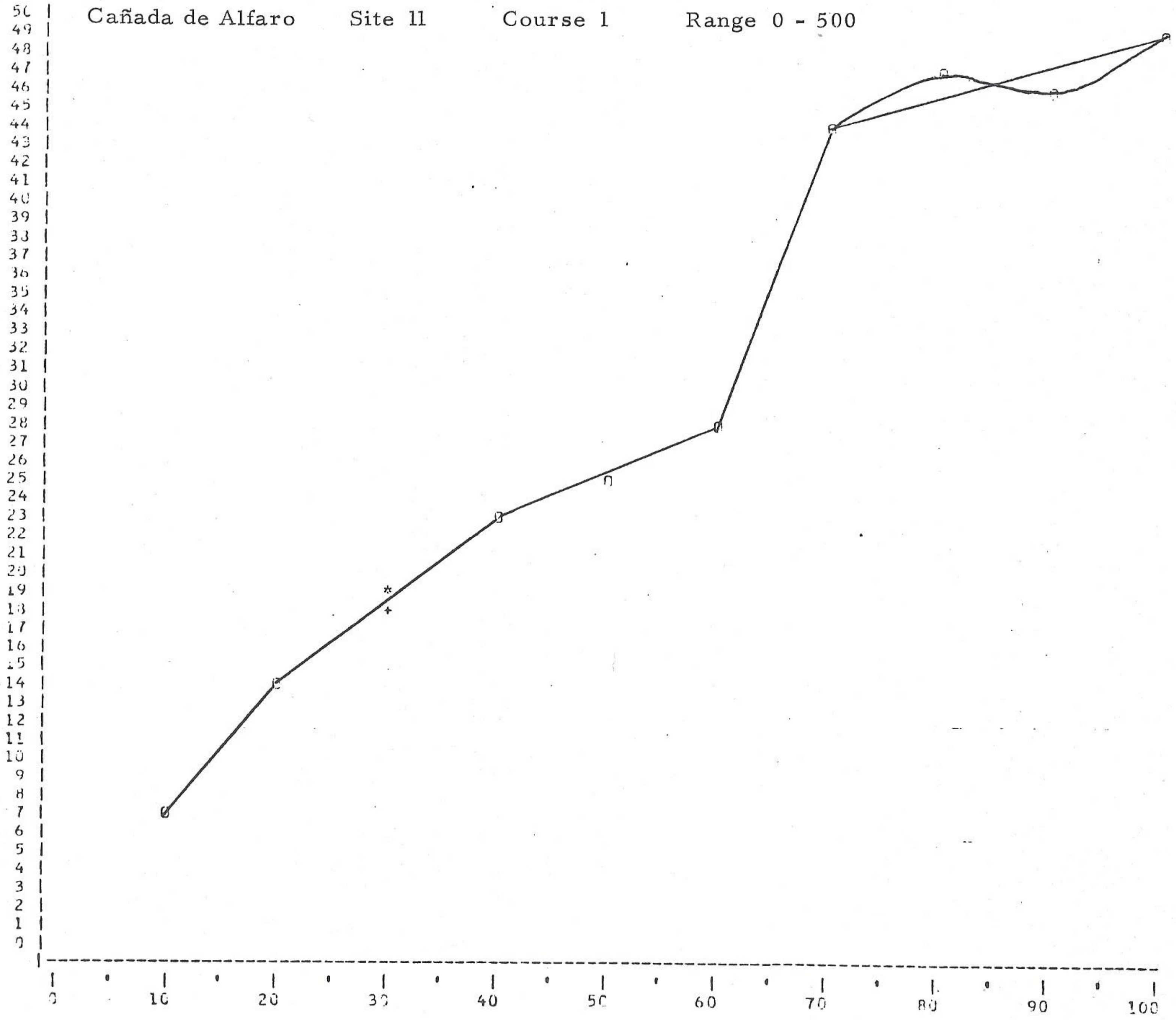


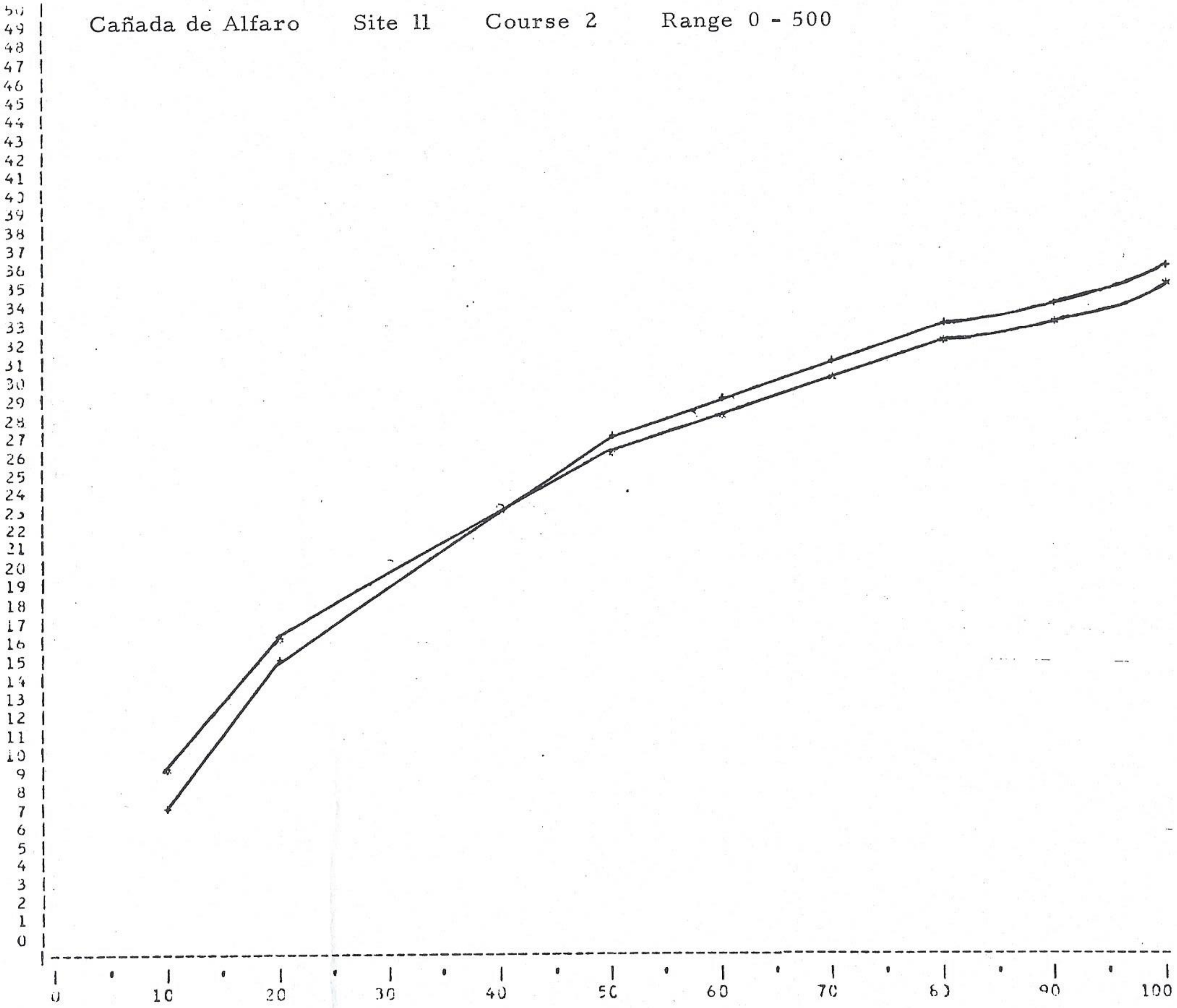
Cañada de Alfaro Sité 22 Course 3 Range 0 - 500



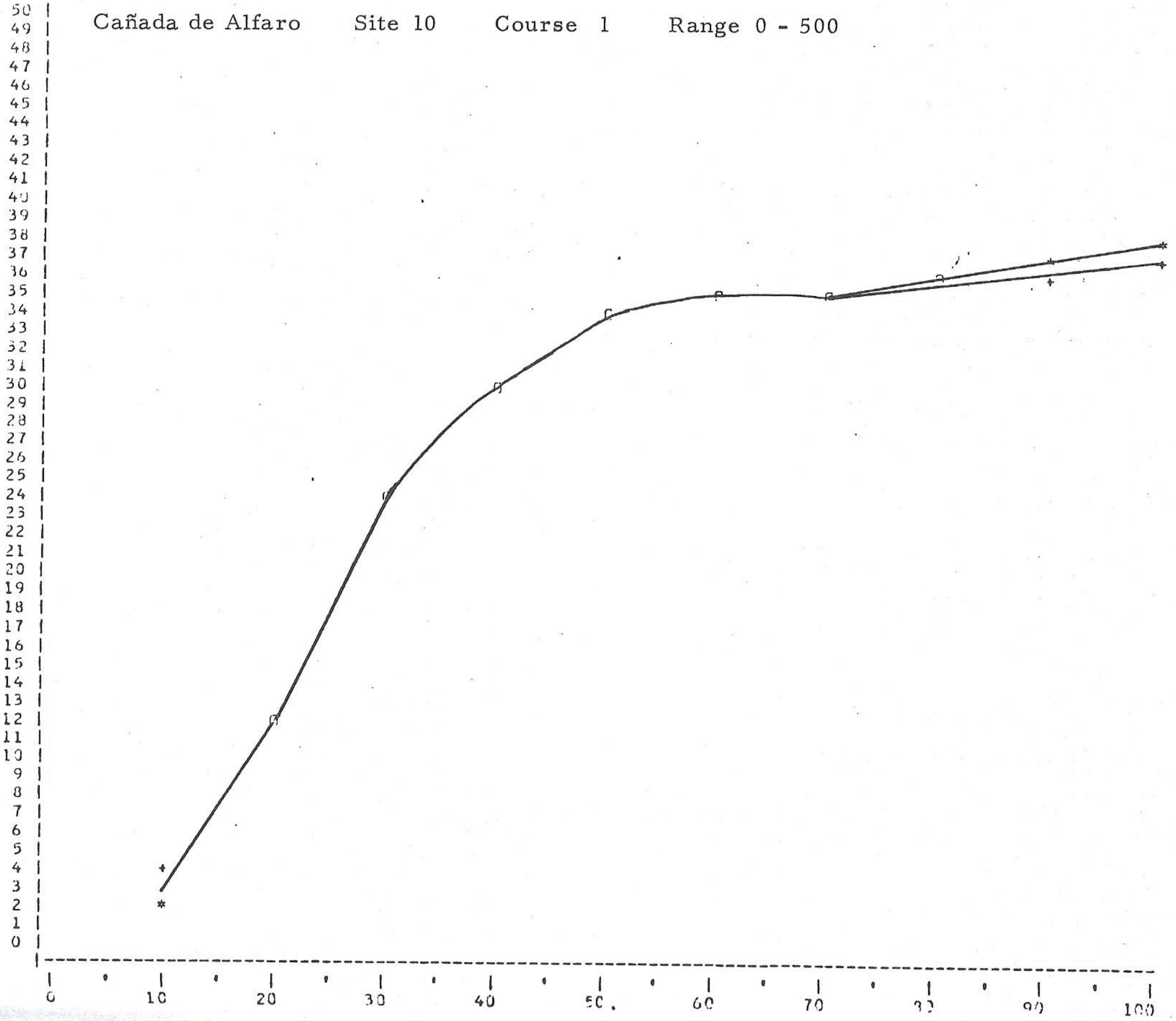
Cañada de Alfaro Site 22 Course 4 Range 0 - 500




Cañada de Alfaro Site 11 Course 1 Range 0 - 500

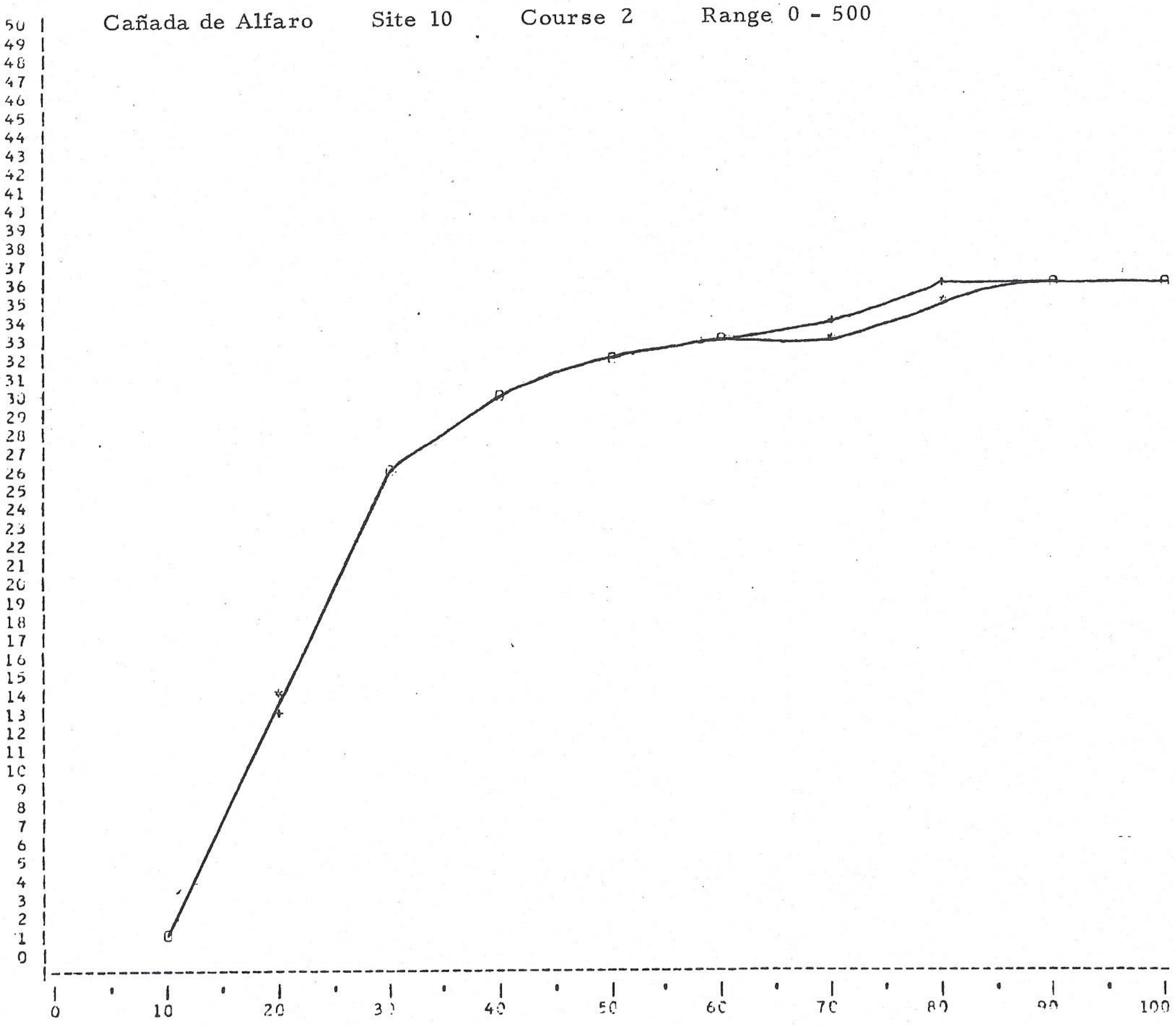


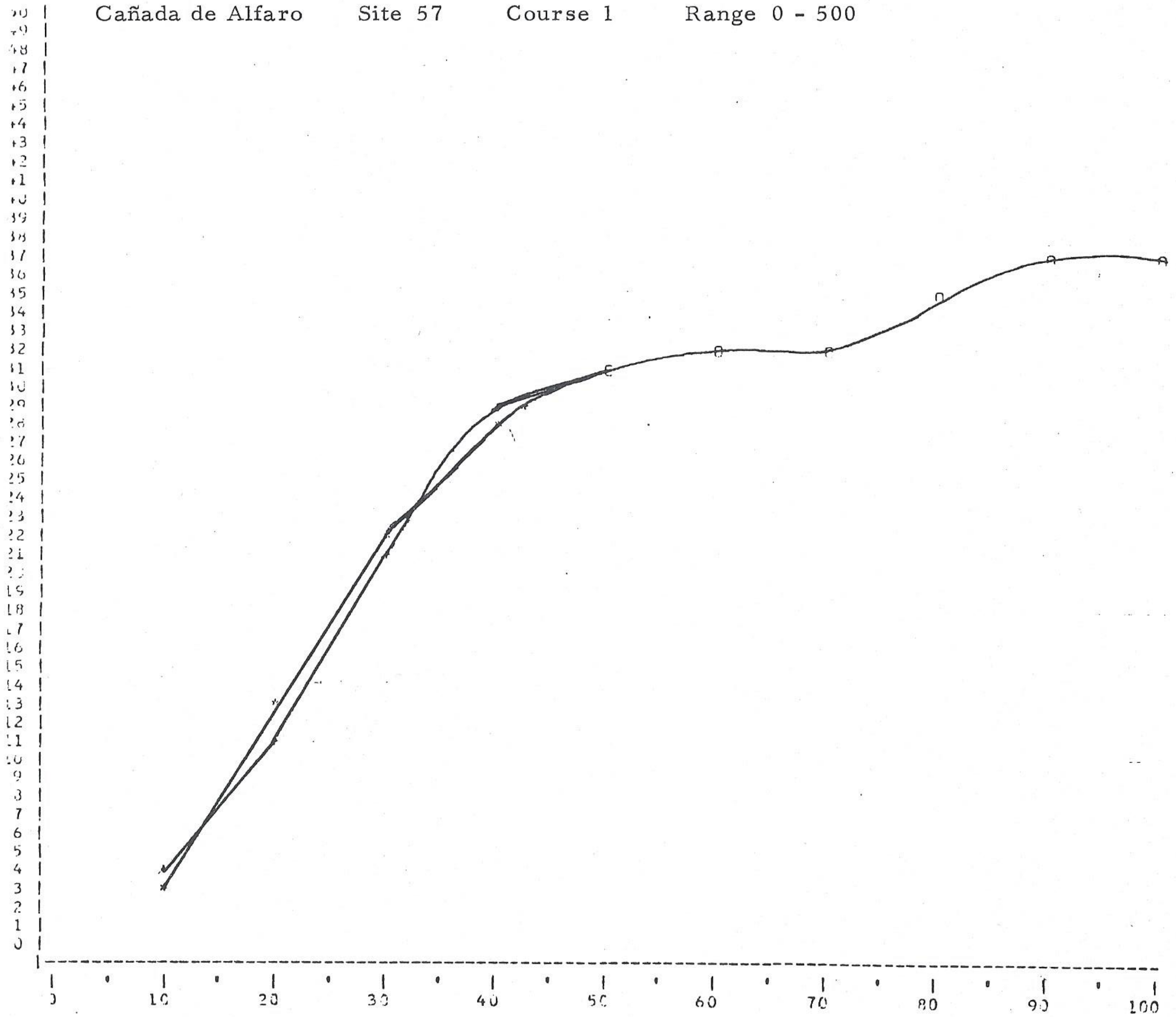
Cañada de Alfaro Site 11 Course 2 Range 0 - 500



Cañada de Alfaro Site 10 Course 1 Range 0 - 500

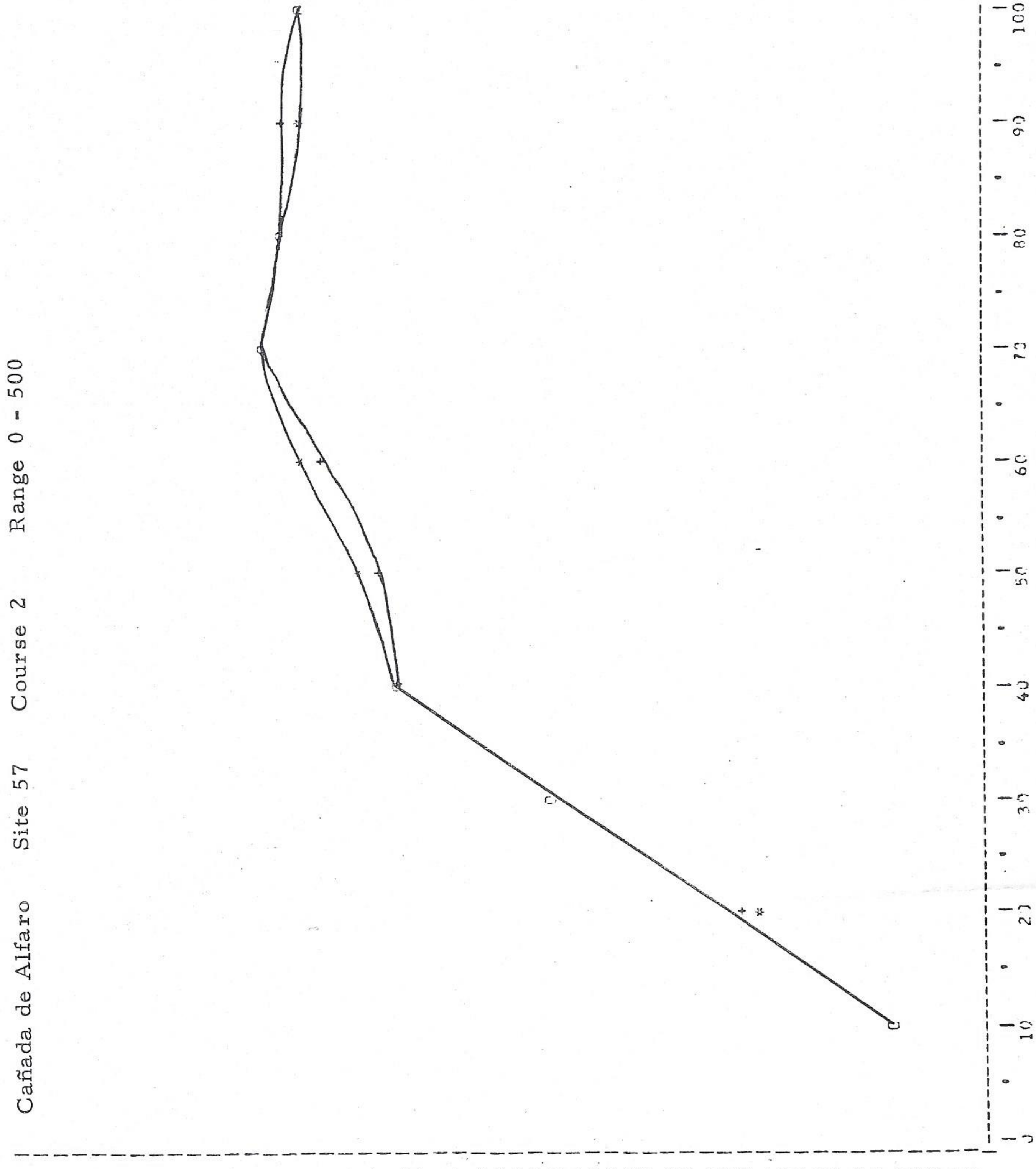
Cañada de Alfaro Site 10 Course 2 Range 0 - 500

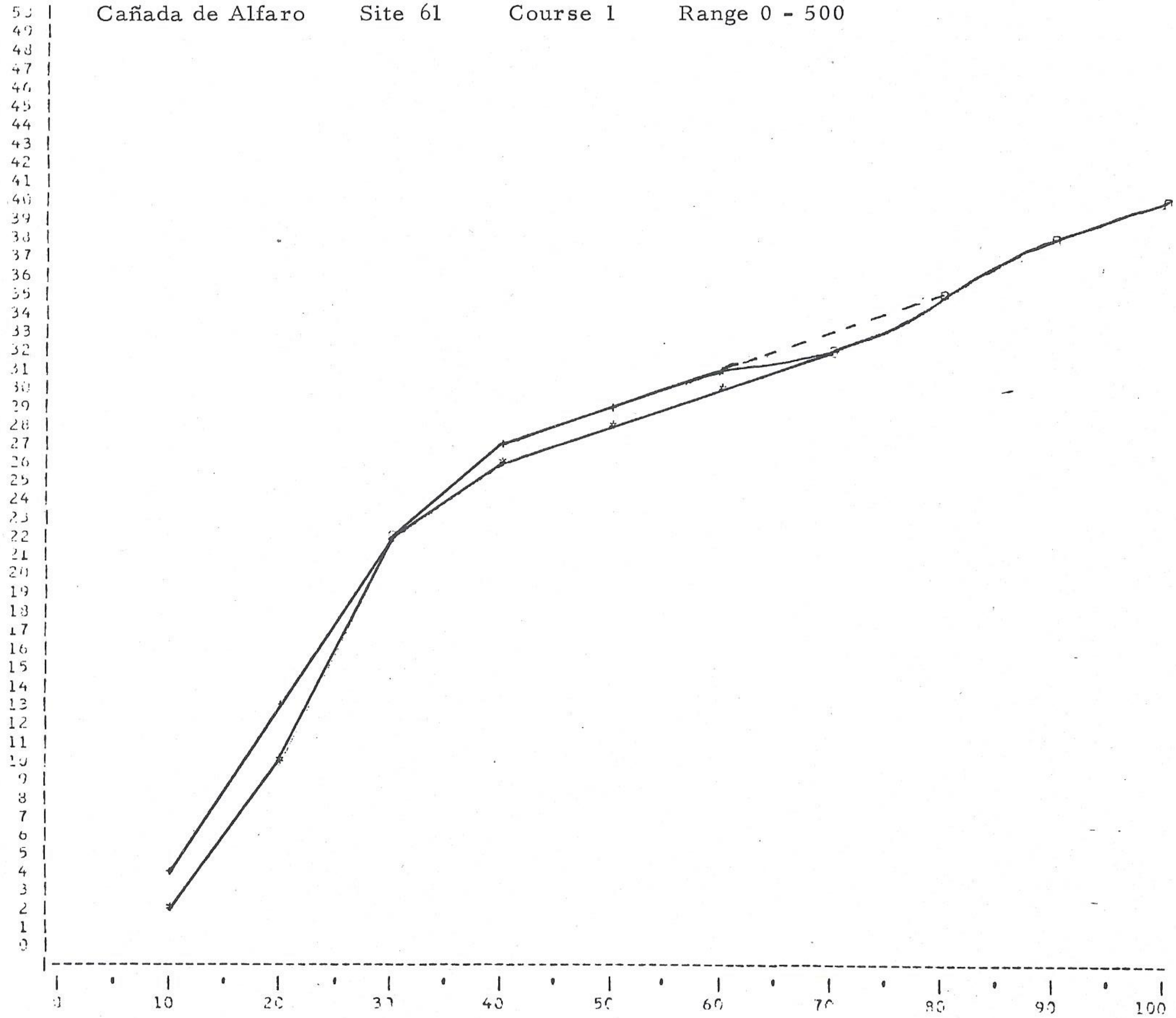




Cañada de Alfaro Site 57 Course 1 Range 0 - 500

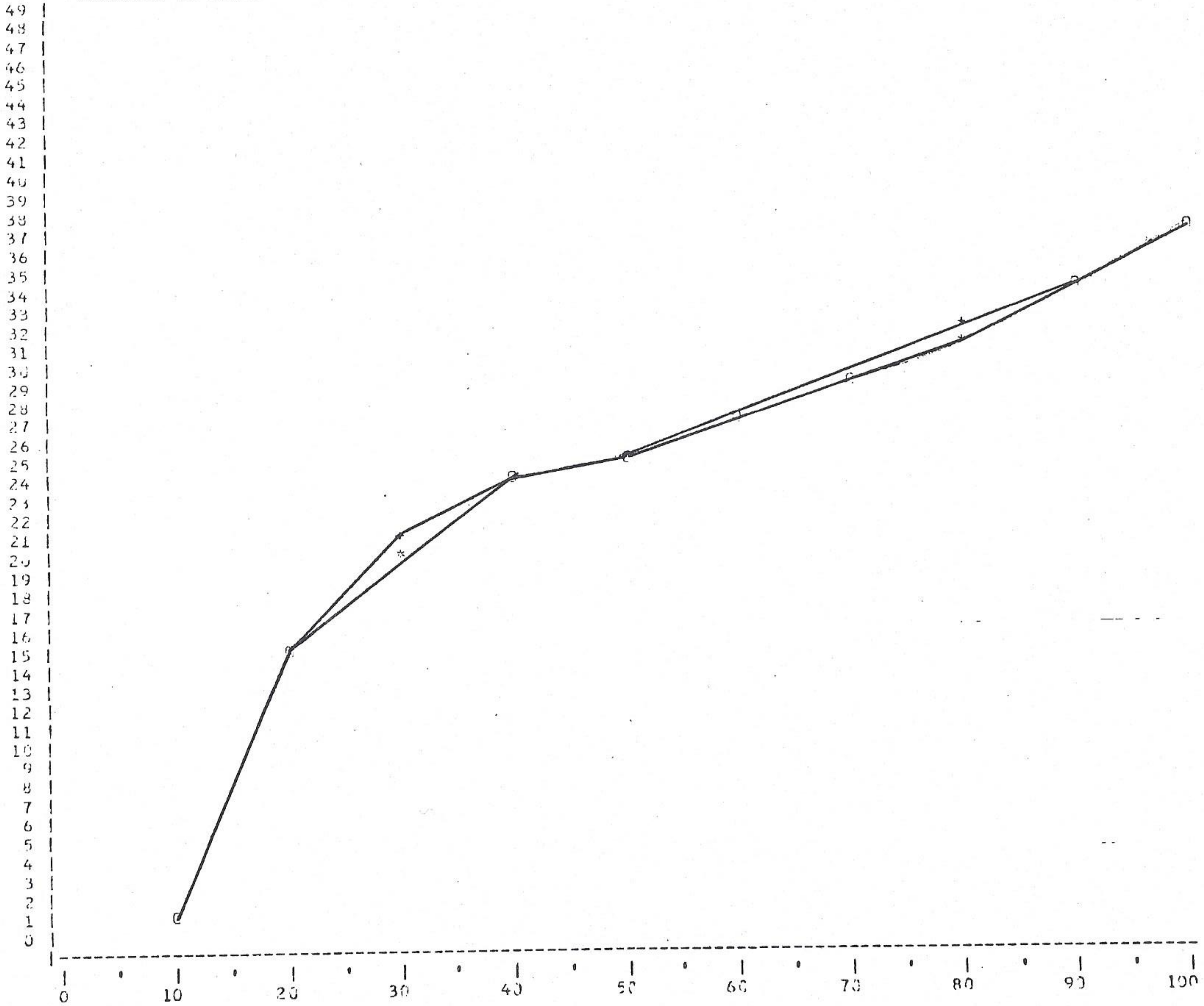
Cañada de Alfaro Site 57 Course 2 Range 0 - 500



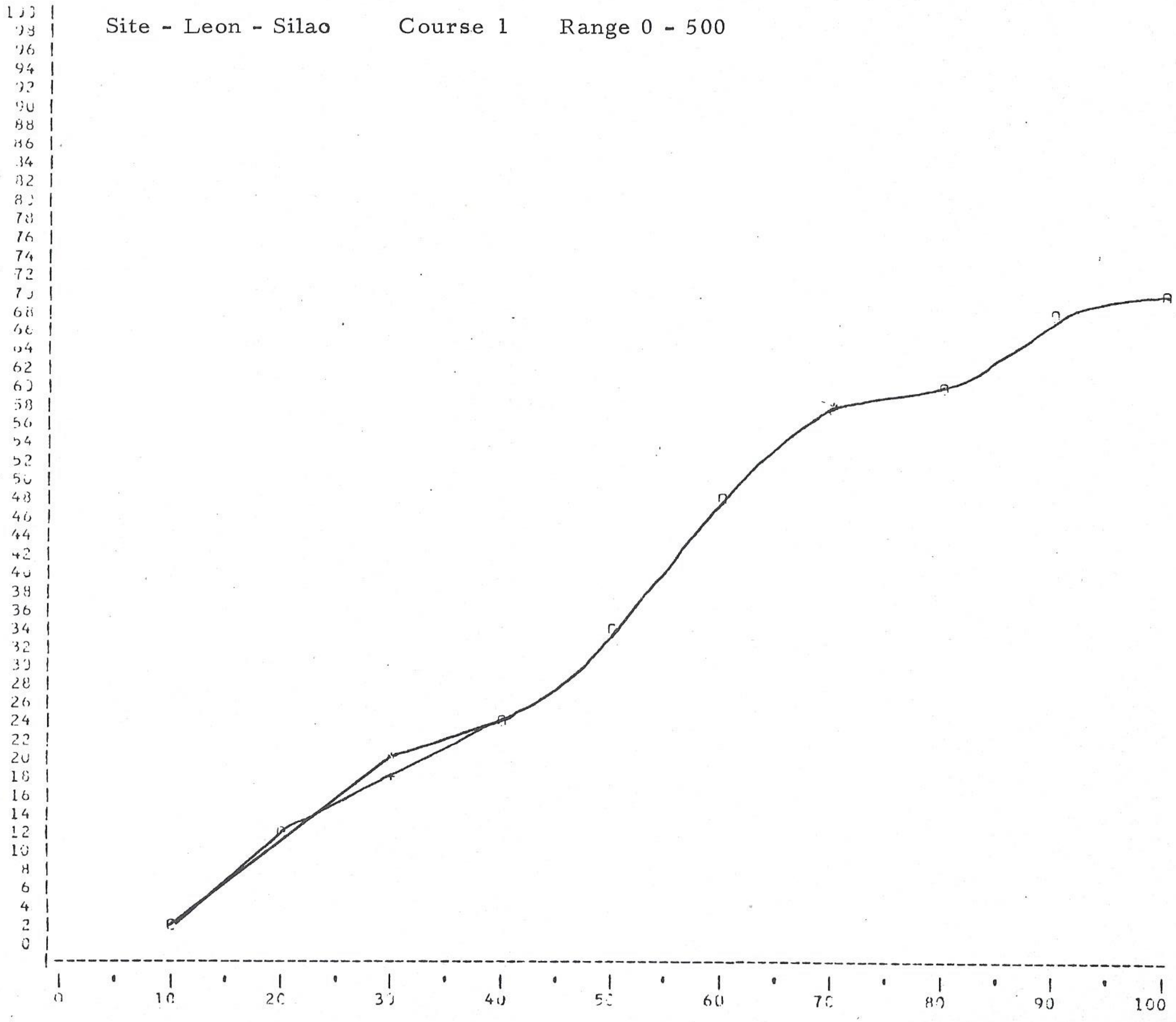


Cañada de Alfaro Site 61 Course 1 Range 0 - 500

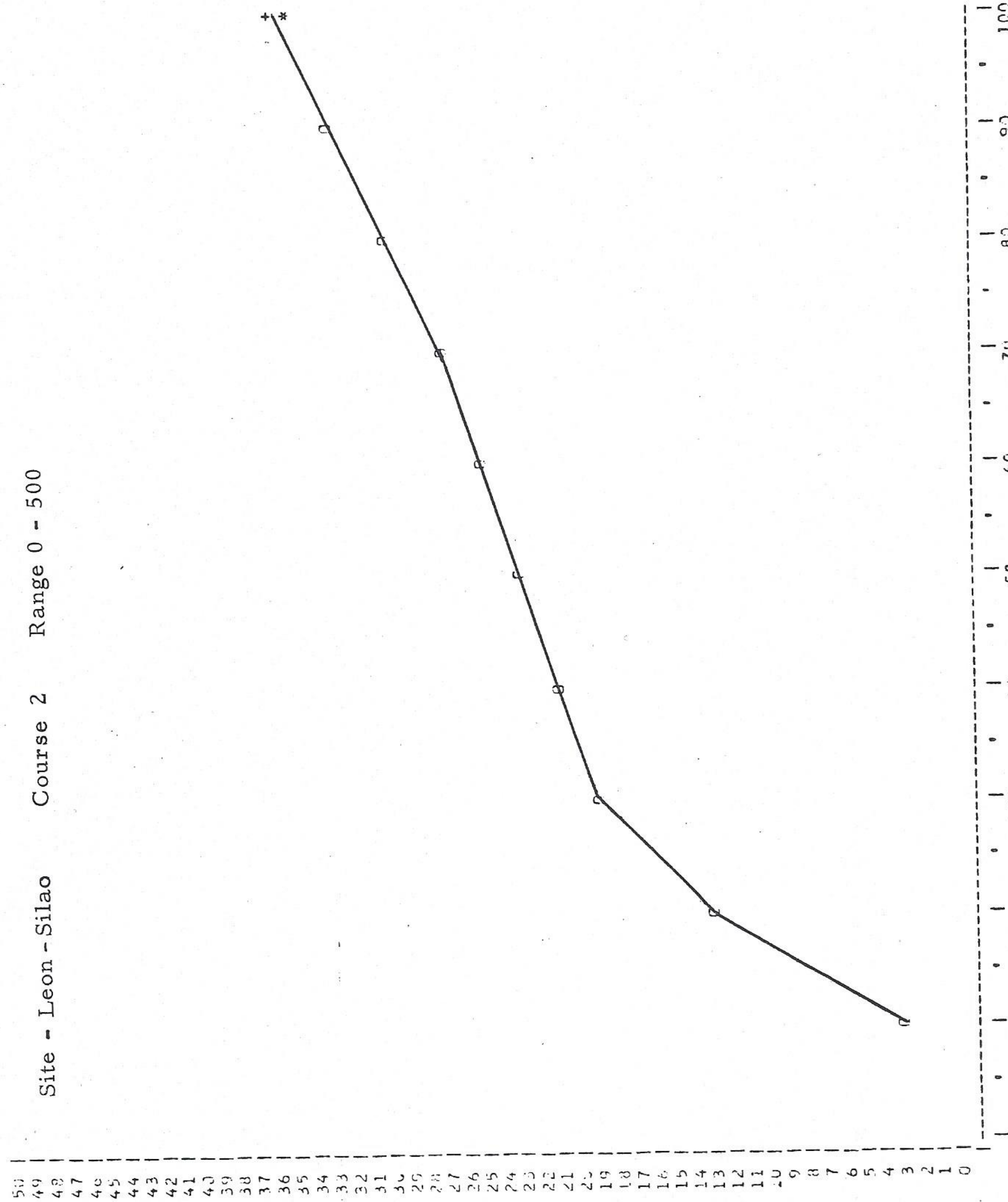
Cañada de Alfaro Site 61 Course 2 Range 0 - 500



Site - Leon - Silao Course 1 Range 0 - 500



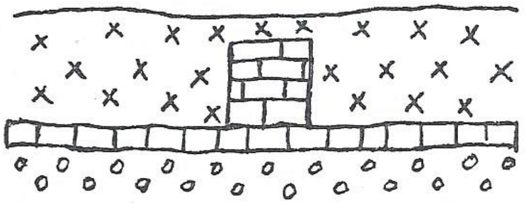
Site - Leon - Silao Course 2 Range 0 - 500

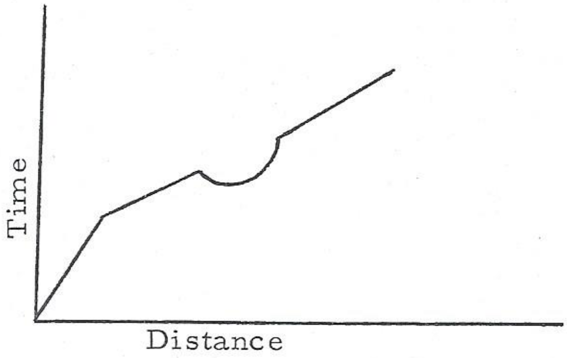


IX. Structural Conclusions

The structural interpretations that follow were based on the hypothetical cases, the real time-distance graphs as plotted by the computer, and general knowledge of the sites.

The assumption supporting these interpretations is that the wave path will follow the structure and will reflect the surface of that structure. For example, in Case 2 of the hypothetical cases, the path follows the wall (assuming that it is wide enough), and the curve in the time-distance graph reflects that wall.



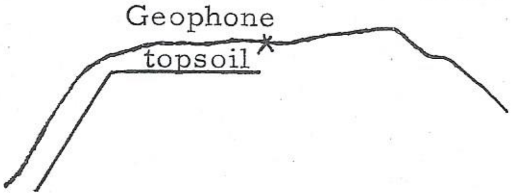


The path follows the floor in a straight line of a certain velocity. As it follows the wall up towards the surface, the velocity speeds up, thus the veering down from the straight line. As it moves down the wall further away from the surface, the velocity begins to slow down again, and as it reaches the level floor, the velocity again resumes the same speed as before. The operating principles (page 91) apply to any case; the shape of the graph reflects the shape of the structure.

It must be made clear that the following interpretations are probably not the only ones possible, but these seemed the "best fit" to real data, and seemed most probable with the interpreter's knowledge of the sites themselves.

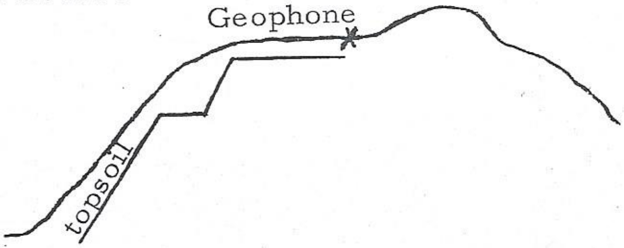
Structural Interpretations

Site Rio Guanajuato - Course 1, Reverse Course:



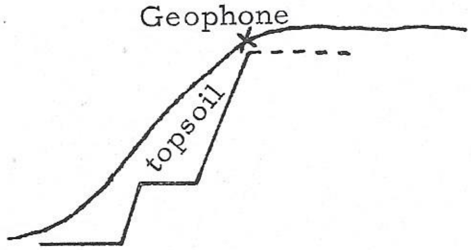
The course ran down hill, and showed a layer of disturbed topsoil down to a depth of 7.345 feet directly under the geophone. At this point it appears to be picking up a single platform of shale or limestone.

Forward Course



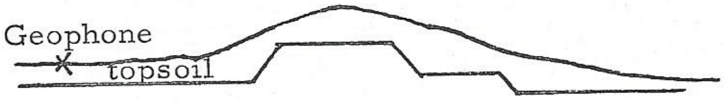
A layer of disturbed topsoil down to a depth of 7.345 feet directly under the geophone, then picking up what appears to be a smaller platform on top of a larger one. The structure continues after the present-day surface levels off.

Site Rio Guanajuato - Course 3

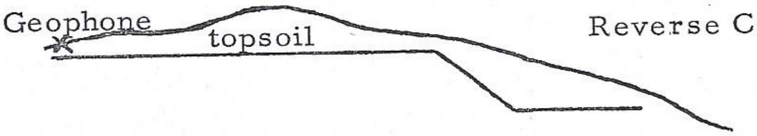


The forward and reverse courses show basically the same structure. The depth of the topsoil is unknown. A structure is detected which appears to be a larger platform on top of a smaller one. Another platform continues where the present-day level of the surface begins to flatten out.

Site Rio Guanajuato - Course 4, Forward Course



The forward course shows a layer of topsoil to a depth of 6.238 feet directly under the geophone. Then a platform is picked up, and the mound on the very top could either be another small platform or a pile of loose boulders. What appears to be two platforms are picked up on the other side, but this could be only a reflection of the damage to the structure where a hole has been dug and several stones removed.

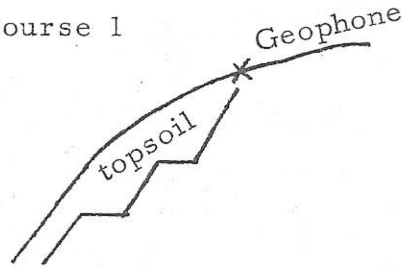


Reverse Course

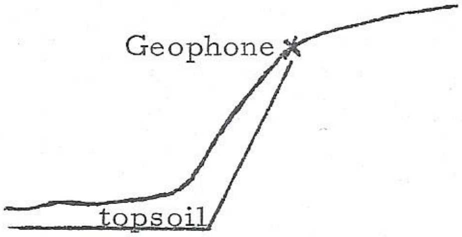
The reverse course also shows a layer of topsoil to a depth of 6.238 feet. In this case, it seems to detect a platform on top of at least one other platform. The smaller mound on top appears to consist of loose dirt from the hole dug on the other side. Again, it is probable that the damage near the end of the course is being picked up, affecting the readings.

Cañada de Alfaro:

Site 43 - Course 1

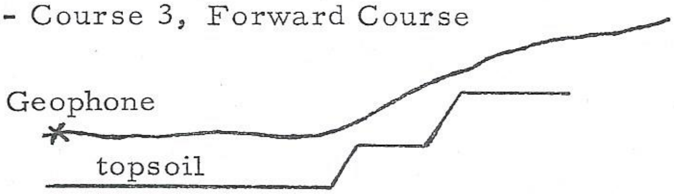


This course shows a layer of topsoil to a depth of 9.06 feet, then appears to pick up three platforms with very badly weathered sides.

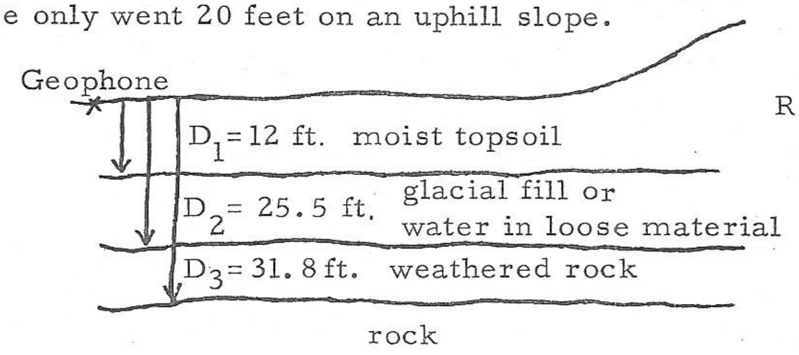


The alternative interpretation also shows a layer of topsoil to a depth of 9.06 feet, but with a single platform on top of a platform after the surface levels off, somewhere around 60 feet.

Site 43 - Course 3, Forward Course



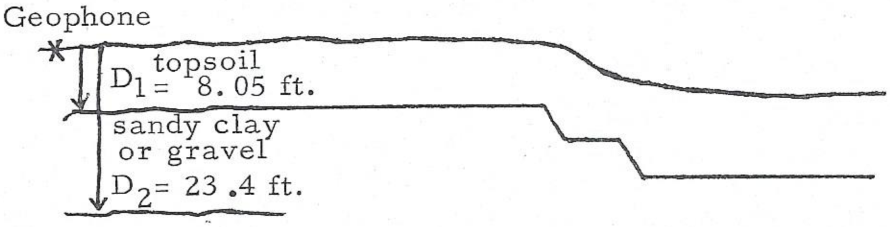
The forward course shows a layer of topsoil to a depth of 12 feet. Then it appears to pick up a platform leading into another platform, all under a relatively flat ground surface. Where the surface begins to slope upward, another platform shows. Its nature remained unknown because the course only went 20 feet on an uphill slope.


Geophone
D_1= 12 ft. moist topsoil
D_2= 25.5 ft. glacial fill or water in loose material
D_3= 31.8 ft. weathered rock
rock

Reverse Course

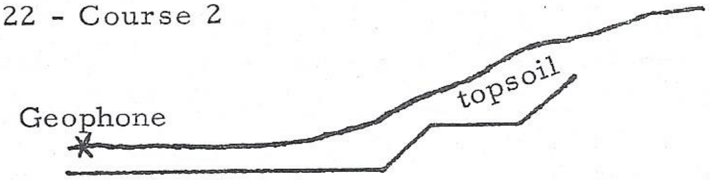
The reverse course shows no structure at all in the plaza, only normal homogeneous layers. However, a portion of a platform is picked up where the course begins to go uphill at a distance of 70 to 90 feet.

Site 22 - Course 1



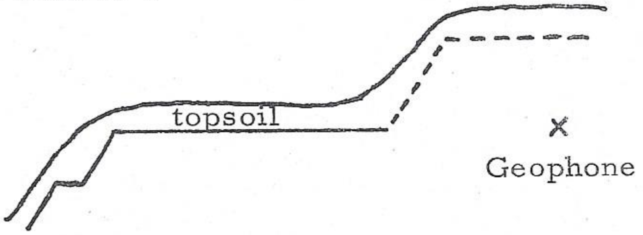
The forward course in this case seems to be the most probable. It appears that directly under the geophone, there is no structure. Here, there is a layer of topsoil to a depth of 8.05 feet, then a layer of sandy clay or gravel to a depth of 23.4 feet. Somewhere around 50 feet, a platform is picked up, which goes down steps onto another platform in a sunken plaza. An alternative interpretation would be that there is no structure at all in this area, but that which is detected is downslope layering over a prehistoric sunken plaza dug into the ground.

Site 22 - Course 2



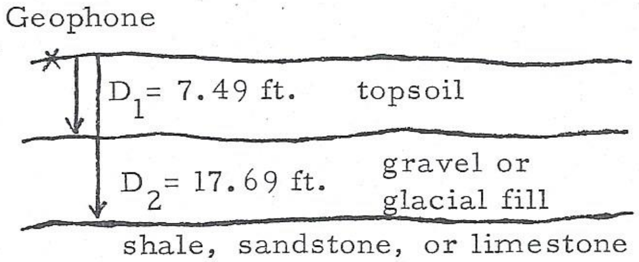
The forward course again seems to be the most likely case. A layer of topsoil to a depth of 2.10 feet directly under the geophone overlies a platform in the sunken plaza. The platform becomes an unknown number of pyramids as the slope of the ground surface goes uphill.

Site 22 - Course 3

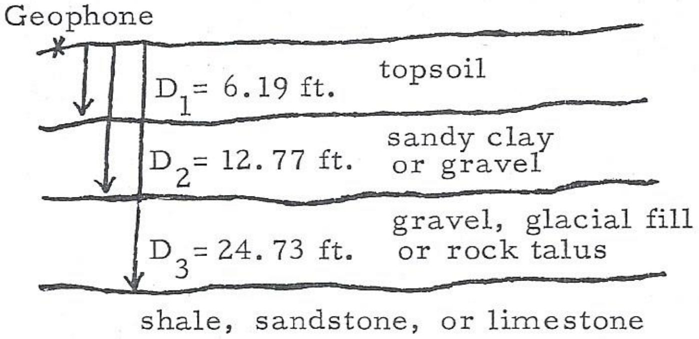


The most likely interpretation for the forward course is that a layer of topsoil is picked up to an unknown depth. Then the pyramid wall is detected to the side of the transect rather than underneath it. Damage to the wall due to pothunting is also detected at the beginning of the course. Somewhere around 100 feet, the pyramid ends and the path jumps down to pick up the platform under the pyramid. The platform continues approximately 130 feet. The course then begins to follow steps down the side of the platform.

Site 22 - Course 4, Forward course

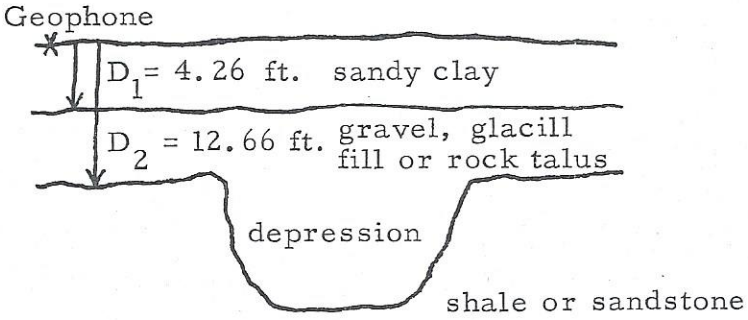


Reverse course



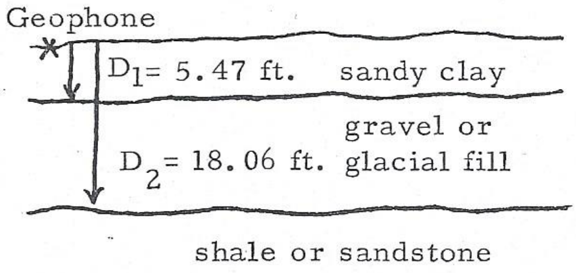
Both the forward and the reverse course show a natural homogeneous layering, and no structures. The only difference is that the reverse course shows one more layer than the forward course, and differing depths.

Site 11 - Course 1



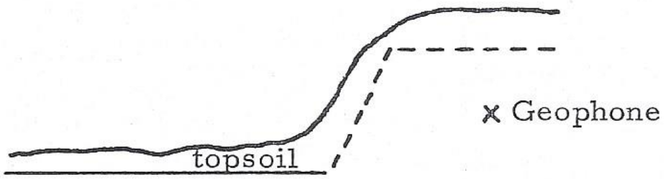
Both the forward and reverse courses show no structure, but a depression somewhere between 50 and 80 feet. The nature of the depression is unknown.

Site 11 - Course 2



Again, both courses show no structures, but homogeneous layers. The curve near the end of the course probably indicates a downslope in the layering.

Site 10 - Course 1



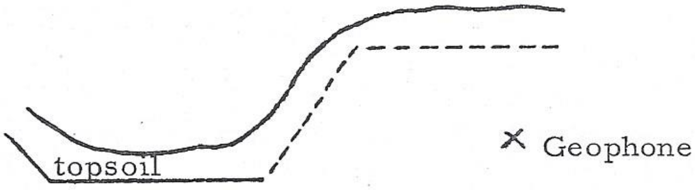
The most likely possibility here is that a pyramid to the side of the transect was detected as the transect moved closer to the pyramid. The structure ended and the natural layer of shale or granite was picked up at an unknown depth.

Site 10 - Course 2

The transect is most likely picking up a structure to the side of it, rather than underneath it, but this interpretation is highly speculative.

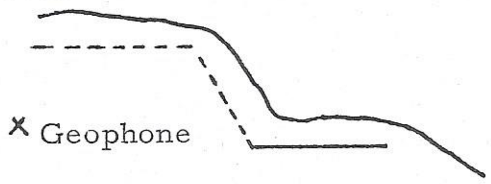
Both Course 1 and Course 2 are probably invalid, as there was a great deal of noise at the site, making accurate readings difficult.

Site 57 - Course 1



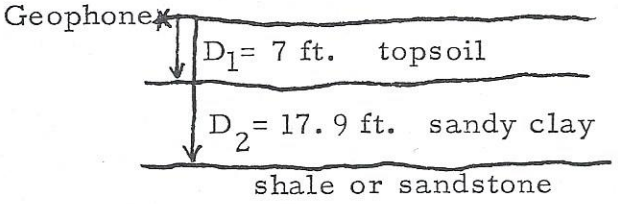
The reverse course shows a layer of topsoil to a depth of 6.93 feet. Then what appears is the wall of a pyramid to the side of the transect as the transect moves towards that wall. A small portion of a platform in the plaza is indicated, then another platform begins as the slope of the surface goes uphill.

Site 57 - Course 2



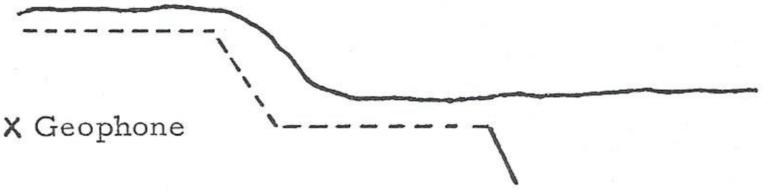
Both courses show a layer of topsoil to an unknown depth. Again, it seems that the path is picking up the wall of a pyramid to the side of the transect, as it moves away from the wall. Then it jumps down to pick up a platform in the plaza, which continues for a short way after the ground surface begins to slope downward.

Site 61 - Course 1, Forward course



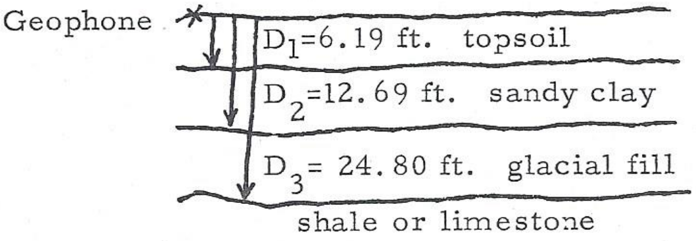
The forward course shows homogeneous layers and no structures.

Reverse course



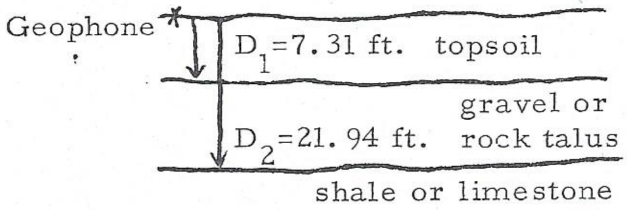
The reverse course would seem to indicate that the wall of a pyramid is picked up to the side of the transect, which is moving towards the wall, then the side of a platform as the transect is going down while the ground level remains flat.

Site 61 - Course 2, Forward course



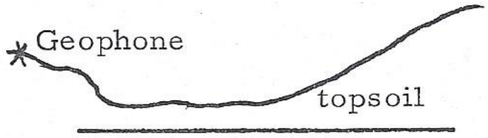
The forward course indicates homogeneous layers and no structures. The curve near the end of the graph could be caused when the transect moves onto the cornfield where the layer of topsoil thickens, i.e. the wave slows down.

Site 61 - Course 2, Reverse course



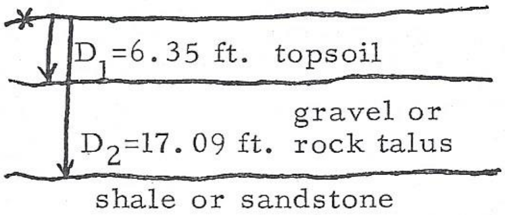
The reverse course also shows homogeneous layers, but with one less layer than the forward course. The same curve, onlyless pronounced, is shown at the end of the graph.

Site Leon-Silao - Course 1



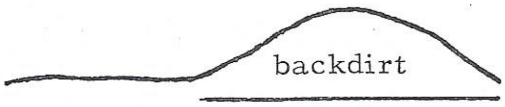
A layer of top soil is shown to a depth of 5.01. This is probably due to the fact that the geophone was placed on what appeared to be a mound of old backdirt. Then a platform seemed to be picked up which continued after the ground surface began to slope uphill. After 70 feet, nothing can be said about the structure because of damage from an old excavation.

Site Leon-Silao - Course 2



This interpretation would indicate homogeneous layers and no structures. The curve caused by the slowing velocity beginning at about 50 feet would be due to the fact that the course goes into a cornfield where the layer of topsoil would be thicker, causing the wave to slow down as it passed through this layer.

Site Leon - Silao - Course 2, Alternative interpretation



This interpretation would show the platform continuing under the pile of old backdirt, the platform ends, and the path picks up the natural bed of shale or sandstone at a lower level under the cornfield.

X. Final Conclusion

Effective use of the seismograph has previously been based on the assumption that subsurface strata are homogeneous, each successive layer being of a higher velocity. However, the investigators of this project were not only interested in the general stratigraphy of the area, but in whether or not subsurface anomalies, i.e., structures, could be detected without having to spend a great deal of time, money, and manpower for excavations. This involved dealing with layers which were not homogeneous, and which were not laid down with uniformly decreasing densities from the lower levels up. Previous investigations have dealt with irregularities or anomalies as 'problems' that must be recognized and accounted for in the interpretations, but which were not interpreted themselves. Therefore, except for the Rainy expedition,[6] this investigation is the first of its kind.

Is it possible then to detect subsurface structures with a portable refraction seismograph? The answer appears to be 'yes,' but with a great many limitations and reservations.

The basic assumption when using the seismograph for archaeological purposes is that a wave will pick up a structure and will follow that structure for the length of the course because the material of a structure will be of a much higher velocity than any layer near that same depth, and thus will be the quickest path for the wave to take. Therefore, the path will never pick up layers below a structure, unless the structure ends. The most common problem in most seismographic work, that of the hidden layer, becomes inrrelevant for our purposes.

Methodology of field procedures

In areas where the subsurface material is unknown, a systematic method of placing the courses, and the number of courses run should be developed in order to reduce the degree of arbitrariness. The best approach seems to be to run four connecting courses, running north, south, east, and west. If more courses are run, for example, systematically covering the entire site, the interpreter could never be sure from where he was picking up structures – from the side, or below the transect, and the plethora of detail becomes too confusing.

Spacing of 10 foot intervals is small enough when one simply wishes to determine the slope of a homogeneous layer. However, when the goal is to follow a specific structure, smaller spacings of 5 feet or less are desirable. This allows the investigators greater accuracy in drawing the graphs by helping to determine if a specific portion was a straight line or a curve.

---

[6] Rainy, "Archaeology and Its New Technology," Science, 153:1490. In the search for the lost city of Sybaris, Rainy reported that seismic instruments were "not suitable for detecting small archaeological features at relatively shallow depths."

Running a reversed course for this type of problem is essential, not for determining average velocities in order to draw a continuous layer, but to validate the shape and slope of the subsurface structure.

Assumptions and limitations for interpretations

In drawing the graphs, it was often difficult to know when to draw a straight line between points - assuming that those points varying from the straight line were due to either variations in the velocity, or variations in the depth of the material through which the wave passes - or whether to draw a curve by picking up every point in the curve. Error of the machine and error of the computer in drawing the graphs by rounding off the readings should also be taken into account.

An intelligent interpretation of velocities on a time-distance graph always requires some knowledge of the area tested. Information about what may be expected will reduce the number of courses required for checks. It is difficult to pin-point a specific velocity for a certain material since the material itself may vary with depth or geographic location. For example, weathered, broken, or seamed rock has a slower velocity than solid rock; clean gravel has a slower velocity than clayey gravel.

In interpreting the graphs, the knowledge of the mound's appearance and the most likely subsurface structures were always kept in mind. The general rule followed was that wherever the course was run over a sloping ground surface, the resulting line would probably be a curve - indicating a structure - unless the points approached a nearly straight line, or unless the surface of the mound was parallel to the general ground surface. Other data was used to help interpret the graphs, such as excavation data, reconstruction drawings, site forms, and general knowledge of the area.

In cases where the time readings varied at the same distance, a line through both points was drawn, and the interpretation allowed for both cases.

The course ended at an arbitrary point, not necessarily at the end of a structure, making it very difficult to interpret the end of the graph correctly. Also, it is often difficult to decide if that which is detected by the seismograph is a structure directly underneath the transect, to the side of it, or running ninety degrees to the course. The only way to decide would be to match up the profiles of cross-connecting courses.

It must be remembered that depth calculations give only the depth of layers directly under the geophone. A different formula must be used to calculate the depth to the structure, and this can only be done if the angles of the structure are known. The general depth formula was used on the graphs until a point was reached where a layer showed a lower velocity than the preceding layer. Otherwise, the velocities of the curves were averaged and used to give the depth of the previous layer.

The exact location of the seismograph must be known and recorded to help create an accurate interpretation. After interpretations are made, they should be tested by excavating in those areas where structures were indicated to validate the interpretations.

It appears that this method for testing for archaeological material may prove to be useful, but further experimentation and refinement of the technique needs to be done. Only in cases where one is working on a specific mound and has other data with which to correlate the seismographically generated data can intelligent interpretations be made as to the shape and location of subsurface structures.

Finally, I would like to express my deep appreciation to all of those people who have helped me on this project, especially Dr. Zubrow, who served as my advisor, Keith Kintigh, who wrote the computer programs, John Justeson, who devised the formulas and explained many of the principles to me, and Andrew Willard, who edited this manuscript. Needless to state, any errors are the responsibility of the author.

BIBLIOGRAPHY

Antoine, J.W. and V.J. Henry. 1965. "Seismic Refraction Study of Shallow Part of Continental Shelf Off Georgia Coast," American Association of Petroleum Geologists Bulletin, 49: 601-9.

Bird, P. H. 1951. "Symposium on the Subsurface Reconnaisance," Special Technical Publication 122, American Society for Testing Material.

Born, W.T. 1960. "Review of Geophysical Instrumentation," Geophysics, 25: 77-91.

Brown, M.V. 1961. "Seismic Refraction Profiles on the Continental Shelf South of Bellport," Geological Society Bulletin, 72: 1693-705.

Currier, L.W, Linehan, and Delano. 1948. "Application of Geology and Seismology to Highway Location Design in Massachusetts," Highway Research Board Bulletin, 13: 66-77.

Duguid, J.O. 1968. "Refraction Determination of Water-Table Depth and Alluvium Thickness," Geophysics, 33: 481-8.

Ewing, J.M. 1959. "Seismic Refraction measurements in the Atlantic Ocean Basins in the Mediterranean, on the Mid-Atlantic Ridge, and in the Norwegian Sea," Geological Society Bulletin, 70: 291-317.

Gaskell, T.F. 1962. "Techniques of Geophysical Exploration," British Journal of Applied Physics, 13: 536-40.

Hill, D.P. and L.C. Pakiser. 1967. "Seismic Refraction Study of Crustal Structure between the Nevada Test Site and Boise," Geological Society Bulletin, 78: 685-704.

Hvorslev, M.J. 1948. Subsurface Exploration and Sampling of Soils for Civil Engineering Purposes. Waterways Experimental Station, Vicksburg, Mass. 465 pp.

Johansson, S. 1961. "The Hammer Seismograph Model FS-2 and Its Use in Finland," State Institute of Technical Research, Finland.

Kaila, K.L. and H. Narain. 1970. "Interpretation of Seismic Refraction Data and the Solution of the Hidden Layer Problem," Geophysics, 35: 613-23.

Kallsen, H.A. 1962. "Seismic Subsurface Exploration," Louisiana Polytechnical Institute.

Layat, G., et al. 1961. "Some Technical Aspects of Refraction Seismic Prospecting in the Sahara," Geophysics, 26: 437-46.

Leet, D.L. 1950. Earth Waves. New York: John Wiley and Sons, 122 pp.

Linehan, Daniel, S.J. 1951. "Seismology Applied to Shallow Zinc Research," Symposium on Surface and Subsurface Reconnaisance. Special Technical Publication 122, American Society of Testing Materials.

Meidav, T. 1969. "Hammer Reflection Seismics in Engineering Geophysics," Geophysics, 34: 383-95.

Meister, Laurent Justin. 1967. Seismic Refraction Study of Dixie Valley, Nevada. Doctoral dissertation, Stanford University.

Musgrave, Albert W. 1967. Seismic Refraction Prospecting. Tulsa, Oklahoma Society of Exploration Geophysicists.

Olhovich, V.A. 1964. "Causes of Noise in Seismic Reflection and Refraction Work," Geophysics, 29: 15-30.

Oliver, T., F. Press, and M. Ewing. 1954. "Seismic Model Study of Refraction from a Layer of Finite Thickness," Geophysics, 19: 388-401.

Palmer, E.M. 1957. "The Gulf Seismic Profile Printer," Geophysics, 22: 286.

Papazian H., T. Searle, and N. Barbir. 1968. "Seismic Subsoil Exploration – Refraction Method Application to Lebanon," American University, Beirut.

Rainey, F. 1962. "Electronics and Engineering Devices in the Search for the Lost City of Sybaris," Illustrated London News, 241: 928-31, 972-4.

Rainey, F. and E.K. Ralph. 1966. "Archaeology and Its New Technology," Science, 153: 1481-1491.

Sander, G.W. and A. Overton. 1965. "Deep Seismic Refraction Investigation in the Canadian Arctic-Archipelago," Geophysics, 30: 87-96.

Shepard, E.R. 1939. "The Seismic Method of Exploration Applied to Construction Projects," Military Engineer, 31: 179.

Shor, G.G. and R.C. Fisher. 1961. "Middle American Trench: Seismic Refraction Studies," Geological Society Bulletin, 72: 721-9.

Shor, G.G. 1967. "Seismic Refraction Profile in Coral Sea Basin," Science, 158: 911-13.

Skinner, E. 1974. "Archaeology and the Portable Refraction Seismograph." Senior Honors Thesis, Stanford University.

Soiltest, Inc. n.d. Terra Scout Model R-150 Portable Refraction Seismograph Instruction Manual. Soiltest, Inc, Evanston, Ill. 15pp.

Stam, J.C. 1962. "Modern Developments in Shallow Seismic Refraction Techniques," Geophysics, 27: 198-212.

Stewart, M. 1971. "The Use of Seismic Refraction in a Route Feasibility Study in St. Lucia," Road Research Laboratory.

Terzaghi, Karl, and Ralph B. Peck. 1948. Soil Mechanics in Engineering Practice. New York: John Wiely and Sons. 729 pp.

Tibbetts, B.L. 1969. "Seismic Refraction Measurements in Jackson Hole, Wyoming," Geological Society Bulletin, 80: 1109-21.

Tuttle, C.R. 1968. "Seismic Surveys for Highway Investigation in Massachusetts," Geophysical Abstracts, 256: 682.

Warren, D.H. 1969. "Seismic Refraction Survey of Crustal Structures in Central Arizona," Geological Society Bulletin, 80: 257-82.

Whitcomb, J.H. 1966. "Shear-wave Detection in Near Surface Seismic Refraction Studies," Geophysics, 31: 981-3.

Zubrow, E.B.W. 1972. "Stanford University Prehistoric Regionalization Monthly Reports." Stanford, Calif.

THE RELATIONSHIP BETWEEN LABOR AND THE SIZE OF SITES IN GUANAJUATO, MEXICO

Elizabeth Skinner

Introduction

During the summer of 1972, an archaeological expedition in Guanajuato, Mexico was directed by Dr. Ezra Zubrow of Stanford University. This work consisted of extensive surveying, with very limited excavation. Seventy-three separate mounds, prospective ball-courts, some plazas, and a road were surveyed. Random systematic sampling was applied to each mound to collect pottery sherds, lithic material, and other artifacts. Areal measurements were taken, measuring the top, sides, and border of each mound. A height measurement was also taken, and the shape of each mound was approximated.

Method

This essay attempts to determine if there are any relationships between the amount of labor invested in each site and the size of the sites, and to see if there are any general groupings of the sites by size. This will be done by calculating the volume of each site and by determining how many man-days of labor were invested in each.

Using the areal measurements, a volume was calculated for each site. Formulas for circular and oval cones, and pyramids yielded a volume in terms of cubic feet. This number was changed to cubic meters because the following experiments in labor investment were conducted in the metric system.

Charles Erasmus (1965) conducted field experiments to test the amount of labor invested in the construction of Maya ceremonial centers. By ethnographic analogy he arrived at a figure of 500 kilos of rocks carried per man-day. This was determined by hiring laborers to excavate and carry earth and rock and measuring the amount of material moved per hour and per man-day (i.e. 5 hours of heavy labor). He estimates that 1500 kilos of rock are used per cubic meter of fill. Each cubic meter of fill would then require about three man-days of labor for the rock content, and he allows one man-day for the dirt content of 500 kilos. He arrives at a figure of one man-day for the excavation of earth and rock, per cubic meter. This gives a total of five man-days needed for the excavation and transportation of one cubic meter of fill, containing both rock and earth.

From what is known, the mounds at Guanajuato are rubble filled, some contain walls of masonry, and therefore the total figures would have to include the amount of time invested in construction of masonry. Erasmus had a Maya stone mason construct a test wall. It was shown that 1400 kilos of rock, 300 kilos of sascab – the material used in mortar, and 100 kilos of lime were used per cubic meter of masonry. He estimated that one-half a man-day per cubic meter of masonry for the sascab content would be maximal, and he uses the previous figure of four man-days for the excavation and carrying of the rock. He allows three and one-half man-days for the manufacture of the lime used in the mortar. This gives a total of eight man-days per cubic meter.

Next, he had two Maya building contractors calculate the time invested in the stone walls of houses they were building. He arrived at a figure of four man-days per cubic meter of construction. This gives a total of twelve man-days needed per cubic meter of excavation, transportation, and construction.

By taking the average between the twelve man-days which includes construction, and the five man-days for excavation and transportation, I decided a figure of eight and one-half man-days invested per cubic meter of fill would be appropriate.

Since the volume was calculated in terms of cubic meters, it was multiplied by 8.5 man-days per cubic meter. This index is the number of man-days invested per site. This figure was then multiplied by 5 man-hours per man-day to give the total number of man-hours invested per site. This number was multiplied by 50 percent to allow for possible room space.

The sites were rank-ordered by thousands of man-days needed for construction. Next, a graph was constructed showing the number of sites per each thousand man-days. It showed that there were four distinct groupings of sites – a large number between 0-4000 man-days, fewer between 4500-7500, one between 12,000-14,000 man-days, and two between 21,000-23,000 man-days. Using these four groups, the chi-square test was applied. It showed that the probability of these groupings occurring by chance is so minimal that it may be legitimately ignored.

Data

Data is given in the following tables.

Table I
Calculations of Volumes, Man-days, and Man-hours

	Volume in feet^3	Volume in meters^3	Number of man-days	Number of man-hours	Number of man-hrs. ÷ 2
Site #1	2379.2	67.37	572.65	2863.25	1431.61
Site #2	5265.1	149.09	1267.29	6336.48	3168.24
Site #3	8639.1	244.62	2079.35	10396.76	5198.38
Site #4	4569.25	129.00	1096.5	5482.5	2741.25
Site #5	9448.53	267.55	2274.17	11370.87	5685.43
Site #6	540.13	15.29	130.00	650.02	325.01
Site #7	1155.2	32.71	278.04	1390.23	695.11
Site #8	12800.00	362.45	3080.84	15404.21	7702.10
Site #9	209.38	5.92	50.39	251.97	125.98
Site #10	5655.56	160.14	1361.24	6806.20	3403.10
Site #11	366.00	10.36	88.09	440.46	220.23
Site #12	137.30	3.88	33.04	165.23	82.61
Site #13	6900.83	195.40	1660.96	8304.83	4152.41
Site #15	14389.69	407.46	3463.46	17317.33	8658.66
Site #16	4599.84	130.25	1107.13	5535.69	2767.84
Site #19	8267.46	234.10	1989.90	9949.51	4974.75
Site #20	5927.24	167.83	1426.62	7133.00	3566.57
Site #21	1908.39	54.03	459.33	2296.66	1148.33
Site #22	92799.08	2627.75	22335.89	111679.48	55839.74
Site #23	25025.82	708.64	6023.48	30117.43	15058.71
Site #26	89427.66	2532.28	21524.42	107622.13	53811.06
Site #27	15339.83	434.37	3693.15	18460.78	9230.39
Site #28	23028.50	652.08	5542.75	27713.75	13856.87
Site #29	7479.97	211.80	1800.36	9001.80	4500.90
Site #30	5808.00	164.46	1397.93	6989.66	3494.83
Site #31	9014.18	255.25	2169.63	10848.15	5424.07
Site #32	22543.90	638.36	5426.11	27130.56	13565.28

	Volume in feet^3	Volume in meters^3	Number of man-days	Number of man-hours	Number of man-hrs. ÷ 2
Site #35	27235.08	771.20	6555.23	32776.18	16388.09
Site #36	3266.66	92.50	786.25	3931.27	1965.63
Site #37	4100.00	116.09	986.83	4934.16	2467.08
Site #41	16255.41	460.29	3912.52	19562.64	9781.32
Site #42	1494.29	42.31	359.66	1798.31	899.15
Site #43	21850.00	618.71	5259.09	26295.48	13147.74
Site #45	10598.61	300.11	2550.98	12754.94	6377.47
Site #47	6893.65	195.20	1659.23	8296.19	4148.09
Site #48	14903.37	422.01	3587.10	17935.52	8967.76
Site #50	1223.18	34.63	294.40	1472.04	736.02
Site #51	50061.71	1417.57	12049.39	60246.99	30123.49
Site #53	7314.91	207.13	1760.63	8803.16	4401.58
Site #54	2733.20	77.39	657.85	3289.28	1644.64
Site #55	3889.64	110.14	936.20	4681.00	2340.50
Site #57	4062.88	115.04	977.89	4889.49	2444.74
Site #58	2015.42	57.07	485.09	2425.46	1212.73
Site #59	4069.17	115.22	979.41	4897.06	2448.53
Site #60	75.41	2.13	18.15	90.75	45.37
Site #63	1323.09	37.46	318.45	1592.27	796.13
Site #69	6403.99	181.33	1541.38	7706.91	3853.45

Table II
Rank Ordered Sites by Number of Man-days

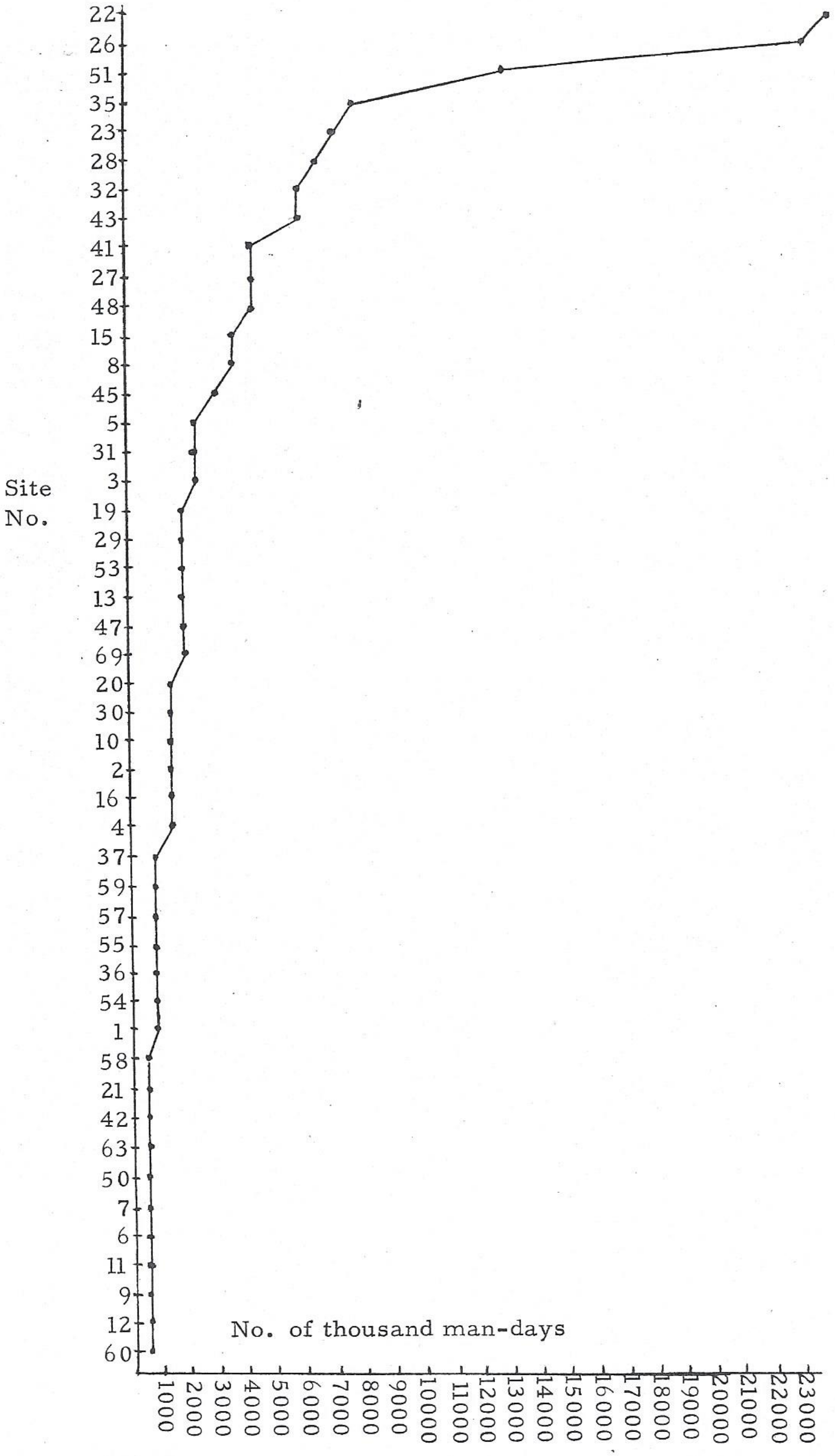


Table III
The Number of Sites per Each Thousand Man-days

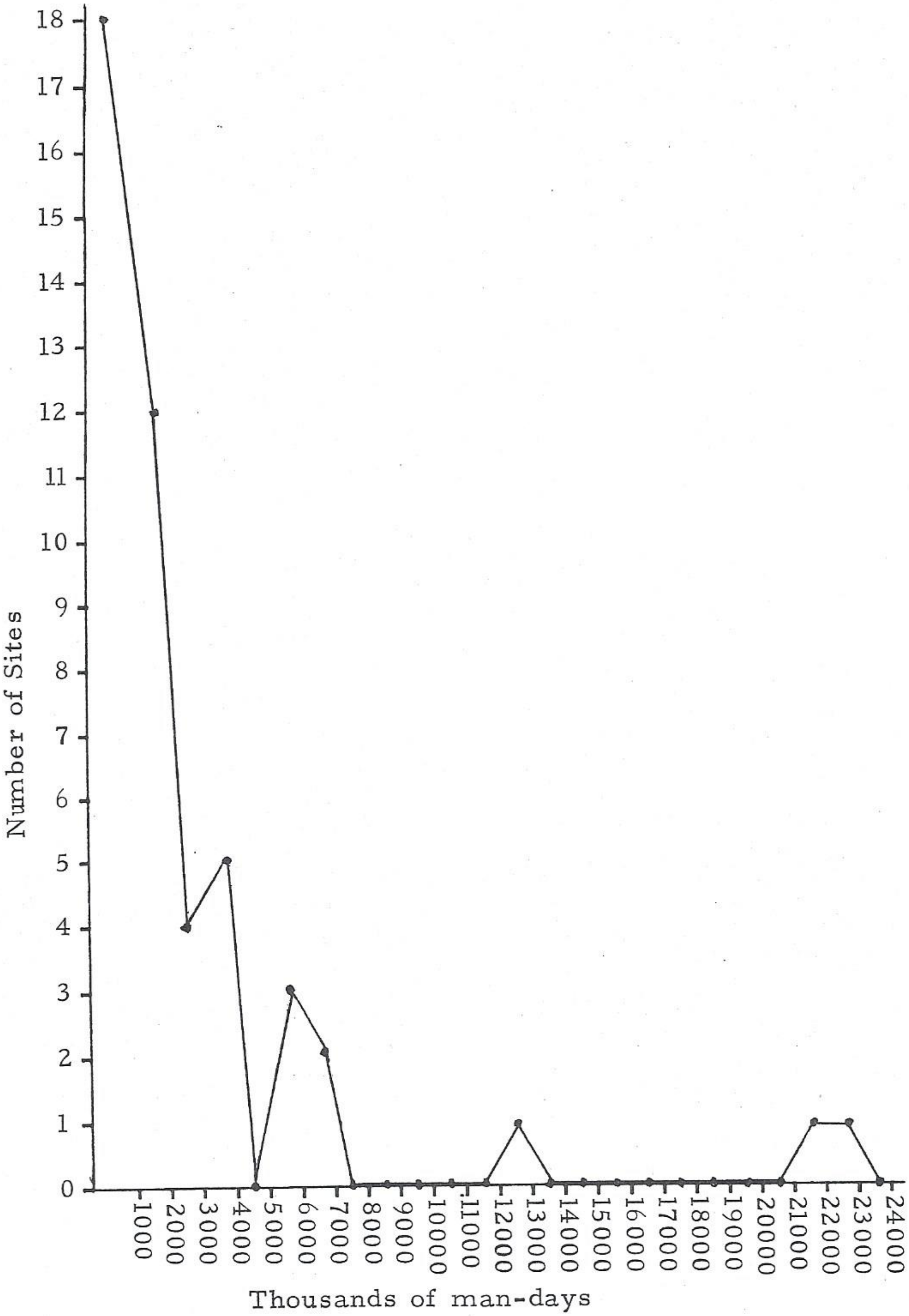


Table IV
Results of the Chi-square Tests*

Test #1 - x^2 = 83.24

p = 1%

Test #2 - x^2 = 320653.82

p = 1%

Test #3 - x^2 = 40.51

p = 1%

* Three different chi-square tests were applied to the same data, all showing the groupings to be significant.

Table V
Totals of Volumes, Man-days, and Man-hours

1. Total volume in cubic feet – 573,363, 98 $ft.^3$
2. Total volume in cubic meters – 16,235.70 $m.^3$
3. Total man-days

   Group I - 0-4000 man-days = 53,292.09 man-days

   Group II - 5000-7000 man-days = 28,806.66 man-days

   Group III - 8000-13,000 man-days = 12,049.49 man-days

   Group IV - 14,000-23,000 man-days = 43,860.31 man-days

   Total - 138,008.45 man-days
4. Total man-hours - 690,038.04 man-hours

Conclusions

Table III shows that these sites fall into distinct groupings, and the chi-square tests indicate that these groupings are not random or by chance. The graphs indicate the inverse relationship between number of sites and labor invested. What is important to note is that the amount of labor invested determines site size, the groupings of sites by similar amounts of labor invested, and the size of these groupings.

One interpretation of these conclusions is that these large sites served some special purpose, such as ceremonial centers. The smaller sites may have been individual house mounds. Therefore, only a few of these large sites would have been constructed, requiring large numbers of man-days. The entire labor force may have been brought together for these community projects, while only small groups would have been needed for the individual projects.

It may be found that the amount of labor invested in a site is determined by the function of the site, i.e., whether it is a common structure or a religious or ceremonial structure. However, this paper deals only with large sites versus small sites, and their relationships to the amount of labor. It says nothing about the actual function of the sites. Further research is needed to test this conclusion. A study of the spatial distribution may give some clues as to whether the groupings of the sites had any special significance or patterns. More excavation would probably show the types of structures at each site. A study of the types of artifacts found at each kind of site would also give clues as to the function of each site.

BIBLIOGRAPHY

Apenes, Ola. 1943. "The 'Tlateles' of Lake Texcoco." American Antiquity, 9.1. 29-32. Menasha.

Cook, S.F. 1947. "The Interrelation of Population, Food Supply, and Building in Pre-Conquest Central Mexico." American Antiquity, 13.1. 45-52. Menasha.

Cowgill, Ursula M., and G.E. Hutchinson. 1963. "Ecological and Geochemical Archaeology in the Southern Maya Lowlands." Southwestern Journal of Anthropology, 19.3. 267-286. Albuquerque.

Edward, Allen L. 1957. Statistical Methods for the Behavioral Sciences. Rhinehart and Company, New York.

Erasmus, Charles J. 1965. "Monument Building: Some Field Experiments." Southerwestern Journal of Anthropology, 21.4. 277-301. Salt Lake City.

Folan, W.J. 1969. "Dzibilchaltún, Yucatán, Mexico: Structures 384, 385, and 386: A Preliminary Interpretation." American Antiquity, 34.4. 434-61. Salt Lake City.

Goggin, John M. 1943. "An Archaeological Survey of the Río Tepalcatepec Basin, Michoacán, Mexico." American Antiquity, 9.1. 44-58. Menasha.

Kaplan, David. 1963. "Men, Monuments, and Political Systems." Southwestern Journal of Anthropology, 19.4. 397-410. Albuquerque.

Millon, René. 1960. "The Beginnings of Teotihuacán." American Antiquity, 26.1. 1-10. Salt Lake City.

Nunley, Parker. 1967. "A Hypothesis Concerning the Relationship between Texcoco Fabric-Marked Pottery, Tlateles, and Chinampa Agriculture." American Antiquity, 32.4. 515-522. Salt Lake City.

Sanders, William T. 1962. "Cultural Ecology of Nuclear Mesoamerica." American Anthropologist, 64.1. 34-44. Menasha.

Willey, Gordon R. 1956. "Prehistoric Settlement Patterns in the New World." Viking Fund Publications, 23. 115-27. New York.

Willey, Gordon R. 1971. An Introduction to American Archaeology, Vol. I, pp. 78-179. Prentice-Hall, New Jersey.

ANALYSIS OF SURFACE SURVEY DATA, CAÑADA DE ALFARO

Emily Wilkins

Introduction

A survey of archaeological sites employing systematic survey design and recording of data was performed during two summers in Guanajuato, Mexico. Seventy three sites were found. A preliminary analysis of 52 variables was recorded across the surface of each site. These data were tabulated (see Appendix A) and then a series of calculations were applied (see Appendix B). The tabulations and calculations are the basis of the following proposals.

Although it is not the purpose of this paper, the data contained in Appendix A may be used for comparisons with other aspects of the total project. These include ecology samples, geographic locations, seismograph data and others.[1]

From the surface survey data, I suggest four proposals about prehistoric activities which took place in Cañada de Alfaro. They are based upon the relationship between ethnographic analogy and the actual distribution of the analytical results of the survey.

Proposal 1

Proposal 1 states that the domestic food preparation area for all 73 sites exists on the East side of the valley. The sites are 15, 16 and some surrounding sites.[2] The most revealing data supporting this proposal is that these sites contain the only hearths in the entire region. A hearth is one of the most essential items for food preparation. A second factor is the relatively scarce amount of broken sherds. This suggests that since utensils are critical for the function of the area, people are more likely to be careful with them. This results in fewer broken ceramic food preparation utensils. The only hand tools found among the entire array of sites were found in this area. Hand tools are another essential item for food preparation. Water is permanently available because the river runs close, but not so close as to infest the area with mosquitos. Another intermittent stream runs close to the sites on the North side. Two more suggestions are 1) these sites are centrally located and easily accessible from all other sites; 2) the hills, which border these sites on the North and East, protect the sites from adverse winds that could easily extinguish food preparation fires.

---

[1] National Science Foundation Grant Proposal for Guanajuato Project, Ezra B.W. Zubrow, Stanford University, 1972.

[2] For a map of the site area see Zubrow's introductory article.

Proposal 2

Proposal 2 suggests that plaza sites are the trade centers for the site community. Two representative sites are 52 and 57 (see map). The primary reason supporting this proposal is that these sites lie close to the river, close to each other, and are located on trails. Rivers have a prominent function in trade and communication. In this case, the river is far too small to carry boats. However, its banks create the easiest areas in which to walk.

The area which contains the plaza sites is separate from, but still within easy access to the area prescribed above as the food preparation area. The separate clustering of the two site types (plaza and food preparation) derives from the necessary separation of two different surpluses. One area deals with a surplus of merchandise for trade, while the other handles the surplus food for the community's immediate consumption. A mixing of the two could result in confusion. Outsiders could intrude on the community and the community could distract prospective traders from their objective. Buying and selling rarely occurs in the domestic area; even if a business is in a home, the two are separate.

Proposal 3

Proposal 3 suggests that the hilltop sites are the lithic workshops. The data show that these sites contain the highest concentration of stone points and chips. Since it is suggested that the trade and food preparation areas are located in the protected valley, it seems probable that the industry would be separate from the two, due to lack of space and undesirability for industry to be close to the domestic area.

There are several advantages to use hilltop sites as workshops. It is easy to defend possible secret methods of production or possible stockpiles of supply. It is possible to see (the data show that these sites have the best visibility) whether or not trade below in the valley is progressing well and thus continue to produce or halt production when necessary.

There is one plaza site located in the hills which could indicate 1) a trade center for prestigious customers or 2) an alternate trade center for when conditions are adverse in the valley (e.g. high mosquito density). Assuming the development of this adversity, regardless of its nature, it is more probable that an alternate trade center would be closer to its industry than to its domestic center.

These sites are the closest spaced of all sites (high density) suggesting that distancing between sites, which may be hard to accomplish on hill sites, was not necessary. Indeed, the most crowded areas today are the industrial centers and business districts.

Proposal 4

Proposal 4 suggests that valley circle and oval sites are housing sites. These sites account for all the remaining sites in the valley which are not already designated food preparation or trade center. They are spaced, within a given region, the farthest from each other (low density) of all site areas examined. This is significant when considered against the contemporary trend that sought after housing has a space buffer zone but is still in contact with the community. The area,[3] or square footage of these sites, revealed an average closely approximating the area of contemporary living units. Other sites are much larger or smaller. These sites are within easy access to the river, thus water is always available for the inhabitants. The most important factors supporting this proposal are 1) these sites lie in a protective valley, 2) are close to a permanent water supply, and 3) are spaced so as to maintain a buffer zone of privacy while remaining within easy access to food preparation, trade center, and industry sites. Finally, these proposed living spaces are on flat ground (0-10 percent slope).

Conclusions

The primary criticism of the data in Appendix A is that it is incomplete for certain variables. This was a result of the exigencies of the field.

In order to formally test proposals 1 through 4, it would be necessary to obtain an independent set of data.

---

[3] The area was not tabulated or calculated in this paper because this study has already been completed for the Guanajuato Project. See the paper in this volume, "The Relationship between Labor and the Size of Sites in Guanajuato, Mexico."

Appendix A

Appendix A includes the list and tabulations of relevant variables. The tabulation charts exclude variables 9, 26, and 29-50 because they were not recorded enough to warrant inclusion in the charts.[4] Variables 21-27 are tabulated in patterns corresponding to the form of the questions in the list of variables.

Variables 21-24 consist of 1) five blade types, 2) four columns indicating the quantity of each blade type. On the tabulation chart, five spaces should be occupied within each box by the letters A, B, C, or D. Whenever a dash occurs in a space within a given box in the tabulation, it is because the variable representing the space was not recorded. The vertical arrangement of the letters in the box corresponds to the vertical arrangement of the five variables in the variable list. This arrangement holds for variables 25 and 27, (see tabulation chart), though the number of letters in the box changes to 3 and 4 respectively.

Variables 6, 28 and 37 were types on separate sheets titled, "Additional Data Sheets" and should be considered as part of the tabulation chart.

Variable 51, in the tabulation chart, shows 5 columns for each site number. These columns correspond to the order of the obstacles as listed in the variable list; river, hill, mountain, rugged, and arroyo. The distances recorded in each box are given in yards unless otherwise indicated (all fractions are in terms of miles). Variable 52 in the tabulation chart has two columns per site. One shows the number of sites visible from the given site; the other shows a letter indicating the shape of the given site (R = round, O = oval, rec = rectangular, sq = square, and Plaza = plaza).

---

[4] This information is included in the calculations (Appendix B) by site group. The information may be found in the original site forms.

Variables Relevant to the Tabulations and/or Calculations

1. Nearest trail
2. Nearby buildings
3. Nearest neighbor sites (# and distance)
4. Type of Holding a) Ejido Plot, b) Pequena Propiedad, c) Hacienda, d) House Plot, e) Other
5. Possibility of Destruction a) Agriculture, e) Erosion, p) Pot hunting, o) Other
7. Type of Site a) Rubble mound, b) Ramada, c) Ceremonial mounds, d) Sherd scatters, e) Activity Areas, f) Houses mounds, g) Chip stone scatters, h) Pit houses, i) Burials, j) Other
8. Exposure a) Exposed, b) Partly exposed, c) Burried, d) Other
10. Condition a) Preserved, b) Part-preserved, c) Rubble
11. Dwellings (#)
12. Construction a) Daub & Wattle, b) Rubble, c) Worked stone
13. Sherds a) very abundant (20/sq. meter), b) moderate (10/sq. meter), c) sparse (5/sq. meter), d) very sparse (1/sq. meter), e) absent

    a) relatively uniform distribution, b) localized, c) variable,
    a) painted, b) textured, c) plain, d) figurines
14. Stone a) very abundant (20/sq. meter), b) moderate (10/sq. meter), c) sparse (5/sq. meter), d) very sparse (1/sq. meter), e) absent

    a) relatively uniform distribution, b) localized, c) variable
15. Perishables a) Textiles, b) Cord, c) Other, d) None
16. Other evidence of construction a) cut stone, b) lajas, c) tepetate d) adobe, e) Other
17. Hearths a) abundant (10+), b) moderate (5), c) few (1), d) none, e) exact #
18. Trash a) % Rock, b) % Bone (animal), c) % Human, d) % Tools, e) % perishables, f) Other
19. Petroglyphs #
20. Tools a) Mano #, b) Metate #, c) Mortar #, d) Pestle #, e) Awls #, f) Scrapers #, g) Other

	a) Abundant (50/sq.meter)	b) Moderate (25/sq.meter)	c) Sparse (10/sq.meter)	d) None
21. Obsidian Blades				
" Scrapers	"	"	"	"
" Cores	"	"	"	"
" Chips	"	"	"	"
" Flakes & other debitage	"	"	"	"
22. Chert Blades	"	"	"	"
" Scrapers	"	"	"	"
" Cores	"	"	"	"
" Chips	"	"	"	"
" Flakes & other debitage	"	"	"	"
23. Slate Blades	"	"	"	"
" Scrapers	"	"	"	"
" Cores	"	"	"	"
" Chips	"	"	"	"
" Flakes & other debitage	"	"	"	"
24. Basalt Blades	"	"	"	"
" Scrapers	"	"	"	"
" Cores	"	"	"	"
" Chips	"	"	"	"
" Flakes & other debitage	"	"	"	"

25. Ceramics:	a) 0-10%	b) 10-25%	c) 25-50%	d) 50-75%	e) 75%+
Preclassic	"	"	"	"	"
Classic	"	"	"	"	"
Postclassic	"	"	"	"	"

26. Trails

27. Agriculture 1) Evidence of a) absent, b) present
2) Irrigation a) River, b) Runoff, c) Reservoir, d) None, e) Other
3) Patterning a) Terracing, b) Waffling, c) Strips, d) None, e) Other
4) % arable land a) 0-10%, b) 10-25%, c) 25-50%, d) 50-75%, e) 75%+

29. Soil Type a) Sand, b) Silt, c) Clay, d) Aeolian, e) Alluvium, f) Gravels, g) Screes

31. Erosion a) Extreme, b) Moderate, c) Slight, d) None

32. Water: Drainage a) Primary, b) Secondary, c) Tertiary
Distance from site a) < 100m, b) < 1 km, c) < 2 km, d) > 2 km
Type a) Spring, b) Reservoir, c) River, d) Lake, e) Other
Type a) Permanent, b) Intermittant

33. Topography a) Valley, b) Valley side, c) Hill, d) Bluff, e) Mesa
f) Mountain, g) Other

Exposure a) North, b) South, c) East, d) West
Slope a) 0-10°, b) 10-20°, c) 20-30°, d) 30-40°, e) > 40°

34. Geology a) Predominant rock type by %

sandstone, shale, limestone, conglomerate, other sedimentary, slate, schistose, marble, quartzite, coal, other metamorphic, volcanic lava, basalt, granite, quartz, other igneous, no predominate outcropping

36. Ecotype a) Desert 1) Cool, 2) Hot, 3) Succulent
b) Chaparral 1) Pinon, 2) Juniper, 3) Aspen
c) Grassland
d) Pine forest
e) Stream edge

% major type a) 0-10%, b) 20-25%, c) 25-50%, d) 50-75%, e) 75%+
Density of ground cover a) 0-10%, b) 10-25%, c) 25-50%,
d) 50-75%, e) 75%+

51. Primary Obstacles in and around a site
1) River a) on, b) near (distance)
2) Hill a) on, b) near (distance)
3) Mountain a) on, b) near (distance)
4) Rugged Terrain a) on, b) near (distance)
5) Arroyo a) on, b) near (distance)

52. Number of visible sites from any given site

TABULATION OF PRELIMINARY ANALYSIS

site numbers	numbers of the variables ....> 1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	27
1.	see Appendix B (graphs) for variables 1,2,&3			c	e a	see Additional data Sheet	a d g	b	c		b	b b c	d a		e					c d c c c	c d c c		all c	d a d	b a c d
2.				c	e		a c	c	c		b	b b c	b b			c1		1	a2	d d d c d	c c c c c	all d ↓	all d ↓	d b –	b a c d
3.				c	a		a d	b	c		b	c b a							a3	l d c l	d c c cc	↓	↓	d b –	b a c d
4.				c	a p		a d g	b	c		b	c b a	a b			c			a4	c c d c	c c d cc	↓	↓	a e –	b d c d
5.				c	a p		a d g f	c	c		b	c d –	c a						a1						b d c e
6.				c	p		a c	c	b		b	d a –	a –						a1						b a c
7.				c	a p		d a g	c	c		b	d c –	c c						a2 b1						b a c a
8.				c	p		a d g	b	c		b	b b c	d b		b	e2			a2						b a c c
9.				c	e a		a	b	c		b	c c	g	d											b a c d
10.				c	e a p		a j		b		b	b b c	b b						a1 f1						b a c d
11.				c	a		a d g	c	c		b	d c c	c c												b a c e
12.				c	a		a d g	c	c		b	d c –	d c			c			a2						b a c e
13.				c	a		a j	b	c		b	d b –	b b		b										b a c d
15.				c	a e		a d g	b			b				d	b4			a g1						b a c e
16.				c	a		a	b	a		b	c b –	c –		e	c			a2						b a b e
Altar				c	p		j	b	b		b					c									b a b –
17.				c	a		d	c	c		b	b a –	b –												b a d –
18.				c			d g	c			b	b a –	c a												b a c d
19.				c	e		a	a	c		b	d a c	a b												a – a –
20.				c	p		a c	b	b		b	c – –	c –		e	e2									a d d a
20road				c			j	b	b		b	d a –	d a												a – –
20plaz				c			j		b		b	d a a	d b		b										a d –
21ball-court				c	p		j	b	b		b	d a c	b –		b										a d – a
21.				c	e		a c	b	b		b	d c –	b c												a d d a
21road				c			j	b	b		b	d a –	d a												a d d a
22.				c	o		c j		c		b	c c d	a a		b		b		g						a d –
23.				c	e a		a	b	b		b	b b –	b b												b b b e
24.				c	e a		a	b	b		b	b – –	b –							c b b b					b b b c
25.				c	e		a	a	b c	a1	b														
26.				c	p		a	c	b		b	– ac –	b a				b a		a b c d						b b d b

	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
27.	see appendix B graphs			c	a	s e e	A	b	c		b	$^{a}\underline{a}$	^{a}a				c									^{b}b b_{e}
28.				c	p a	a d d	A	b	c		b	$^{b}\underline{a}$	^{b}b													$^{b}\underline{\underline{b}}$
29.				c	p e a	i t	A	a	c		b	$^{c}\underline{a}$	$^{b}-$		e				b							b_{b} c_{c}
30.				c	e	i o n	A	b	c		b				e											
31.				c	a	a l	A	c	c		b	$^{c}\underset{c}{b}$	^{b}b		e											b_{b} d_{b}
32.				c	a	d a	a	b	c		b		^{a}b	d												b^{b} d_{c}
33.				c	a e	t a	^{d}g	c	c		b	$^{b}\underset{a}{c}$	^{b}c	d			a_{g}									b_{b} c_{d}
34.				c	e a p	s h	^{d}e	c	c		b	$^{c}\underset{a}{c}$	^{a}c	d			a									b_{b} c_{d}
35.				c	e a p	e e t	^{a}d	c	c		b	$^{b}\underset{a}{c}$	^{c}c	d			a									b_{b} c_{c}
36.				c	e a p		$^{a}d_{g}$	b	c		b	$^{b}\underset{a}{c}$	a_{c}	d	e				e_{f}							b^{b} c_{d}
37.				c	a		^{d}g	a	c		b	$^{c}a_{e}$	^{c}a						a_{b}							b_{b} a_{d}
38.				c	e		e	b	c		b			d												a_{b} $-_{a}$
39.				c	a		^{d}g	c	c		b	$^{b}\underline{c}$	$^{b}-$	d												b_{d} $-_{e}$
40.				c			^{d}g	c	c		b	$^{b}\underline{c}$	$^{b}-$													b_{d} $-$
41.				c	o		a	c	c		b	$^{a}\underline{b}$														b_{b} $-_{e}$
42.				c			a	c	c		b	$^{d}\underline{a}$	^{d}a	d					f							b_{d} b_{b}
43.				c	p a		^{a}c	b	c		b	$^{d}_{c}a$	^{d}a		e				a1							b_{d} c_{b}
44.				c			^{d}g	a			b	$^{c}=$	$^{b}-$	d												b_{d} b_{-}
45.				c	e		a	b	c		b	$^{-}\underline{a}$	$^{b}-$													$b_{=}$
46.				c			d	c			b	$^{b}=$		d												$b_{\equiv}$
47.				c			a	c	c		b	$^{c}=$	$^{d}-$						d1							b_{d} d_{e}
48.				c	e		a	c	c		b	$^{b}\bar{c}$	^{c}a						a5							$b_{=}$
49.				c	e a		^{d}g				b	$^{b}\bar{c}$	$^{c}-$						a1							b_{d} d_{e}
50.				c	e a		a	c	c		b	$^{c}=$	$\underline{c}$													$b_{=}$
51.				c	e a		a	c	c		b	$^{c}=$	$\underline{c}$													$b_{\bar{e}}$
52				c	e a p		d	c	c		b	$^{d}\underline{c}$	^{d}c						a1 f1							b_{a} c_{e}
53.				c	e a p		^{a}d	c	c		b	$^{d}\underline{c}$	^{d}c						a1							b_{b} c_{d}
53p				c	e a p		j				b	$^{b}\underline{c}$	^{c}a													b_{b} c_{e}
54				c	e a		a	c	c		b	$^{c}=$	$^{c}-$													$b_{\bar{e}}$
55.				c	e a		a	c	c		b		$\underline{c}$													$b_{\bar{c}}$

	1	2	3	4	5	6	7	8	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
56.	see appendix B graphs			all + C	e a	see additional data sheet	a	c	c			c =	c -													b ≡
57.					e a		d		c			b =	b -													b = e
57p					e a		a	c	c			c =	c -													b = e
58					e a		a	c	c			c =							a1 d1							b = e
59					e a		a	c	c				c -													b = e
60					e ap		a	c	c			c =	c -													b = e
61					e a		d	c	c			b =	b -													b = e
62					a		d					b =	d -													b = e
63							a	c	c			c =	c -													b = e
64					a		d					b =	c -						a1							b = e
65					a		d					c =	d -						a1							b ≡
66					a		d					b =	c -													b c b e
67					a		d					c a -	c a	d												b a b e
68					a		d					c a -	c a	d												b a b e
69					a		d	c	c			b =	c -						a1 b1							b c e
71					a		d					c a -	d -	d												b a b e
73a					a		d					c a -	c a	d												b a b e
73b					a		d					b a -	c a	d					a1							b a b e

	RIVER 51	HILL	MOUNTAIN	RUGGED ARROYO	51cont.						51cont.						52			52					
1	100	1 mi	-	-	25	---	---	---	---		53 p	---	---	---	---		1	1+	R	25	---		53p	5+	R
2	800	"	-	-	26	35	500	---	---		54	on					2	1		26	3	?	54	5	rec
3	¼mi	1mi	10 mi	-	27	250	300	---			55	on					3	3	o	27	1	R	55		rec
4	"	"	"	"	28	250	300				56	---	---				4	3+	O	28	1	O	56	5	rec
5	"	"	"	"	29	50	300				57	on					5	4+	R	29	3	R	57	5	plaza
6	¼	¼	10	"	30	100	400				57 p	on					6	6+	R	30			57p		
7	¼	1	10	"	31	200	200				58	on					7	7+	rec	31	9	0	58	5+.	R
8	¼	½	1¼	¼	32	1mi	on				59	on					8	4	rec	32	0	0	59	5	0
9	50	½		½	33	1	½				60	50					9	9	rec	33	4	R	60	5	0
10	½	1	1½	60	34	1	½				61	80					10			34	2	rec	61	5	rec
11	60	½		½	35	1	½				62	200					11		sq	35	2	R	62		R
12	200	½		½	36	1	¼				63	100					12	9	R	36	-	rec	63	1	0
13	---	---	---	---	37	2+	200				64	---					13			37	0	rec	64	1	R
14	---	---	---	---	38	---	---	---	---		65						14			38	2	R	65		R
15	200	½	½		39		100				66	50				on	15	2	0	39	2	R	66	1	0
16	---	---	---		40		100				67	300					16		R	40	3	R	67		rec
Altar	---	---	---	---	41		100				68	300					Alt	3	R	41	3	R	68	1	R
17	---	---	---	3	42		on				69	50					17	1	sq	42	1	rec	69		R
18	400	600		350	43	200	¼				71	300					18	1	?	43	2	rec	71		R
19	1mi	---	---	---	44	10	100		100		73						19	3	R	44	3	rec	73		R
20	on			on	45	on	200				73 B	150					20	1	R	45	-	rec	73 b	1	R
20R		on		on	46					200							20R			46	1	0			
20P	1	on	10	100	47	400											20P			47	0	0			
21B	1mi	on	5mi	on	48	200	200										21B	3		48	2	rec			
21		on		on	49		200										21	3	R	49	5	0			
21R		on		on	50	---											21R			50	5	0			
22	150	250		350	51	on											22	3+	?	51	7	rec			
23	100	50		on	52	on	½										23	2	?	52	9	R			
24	150	20			53	100	½										24	2	0	53		rec			

Additional Data Sheet for Variable 6

Sites

1) xxx

2) Irregular mound indented in the middle of a large mound. Mesquite and cactus on it. Used by farmers for shade.

3) In cornfield with tree - depression on second small mound.

4) xxx

5) Very small low mound with undifferentiated sides and top. Increase in the number of lithics and ceramics in the middle of the field near an oak tree.

6) xxx

7) xxx

8) Getting into a cluster of sites. Surrounding field richer as work moves toward the river.

9) xxx

10) xxx

11) xxx

12) xxx

13) Partially destroyed by path and wall across it.

14) xxx

15) Discrepancy as to whether there are one or two sites due to apparent wash area in between top ones.

16) There is a terrace not included or part of the site, but which is drawn.

Altar 1 near the river.

17) Very near dry river ravine. Cornfield with contour and high density (material) on NE side.

18) Cornfield with no noticeable slope.

19) Earth has washed away a higher point exposing rock.

20) Top of hill. The top has illegal excavation and the material from inside is scattered on top.

20 Road) This road runs down the hill towards the site (from site 20) 850' long and 5'6" wide.

20 Plaza) Plaza is west of mound.

21 Ballcourt) Possible Ballcourt 60' x 12'.

21) xxx

21 Road) 549' long, downhill from site 21 same width as 20 road.

22) Holes dug in top.

23) xxx

24) xxx

25) See mound cut.

26) Secondary mounding.

27) xxx

28) Side 1-5 are questionable since they fall into the 27/28 border.

29) xxx

30) xxx

31) Part which has been undisturbed by plowing has been covered with new rocks.

32) Middle and S side will probably continue to be covered by new rock.

33) In middle of fallow field. Very rocky with clay or lava soil. Very exposed, no mounding. Both sherd and ceramic concentration.

34) In field across arroyo from 33.

35) Adjacent to 34 and 33. A small field above field which appears to be workshop area.

36) In middle of fallow field. Obvious mound with both sherds and lithics.

37) Terraced cornfield. Cactus shrub to W.

38) No mounds or abundance of ceramics or lithics – only 3 samples taken.

39) In valley E of shoulder of full hill.

40) xxx

41) Stone walled well 60' deep in center.

42) xxx

43) xxx

44) Large lithic concentration. No mounding, therefore no samples for the top and side.

45) xxx

46) xxx

47) xxx

48) Circular.

49) Only sherd scatter.

50) Small site, almost part of 51.

51) Seems to be along terrace edge along with several other sites.

52) Mound evident from field tq south and no mounding on plane plaza.

53) On terrace w/ 51, 52.

53p) xxx

54) Modern rock cover make sampling impossible.

55) This site is right next to excavation site 43 to W.

56) 300 yds W of site 43.

57) xxx

57 Plaza) 5 samples taken from plaza which lies between 57 and 58.

58) xxx

59) One large pothole, most samples taken on border.
60) xxx
61) xxx
62) Sherd scatter - 5 samples.
63) xxx
64) Treated as sherd scatter due to modern rocks.

65) xxx

66) xxx

67) xxx

68) xxx

69) Large sherd scatter to S not included in claculations or collections.

71)-73B) xxx

Additional Data Sheet for Variable 28

Sites

1) xxx
2) xxx
3) xxx
4) More lithics than pots on North side, more pots on S.
5) xxx
6) xxx
7) Debitage and pottery piled in one spot. Definite disturbance.
8) Middle of site is being excavated.
9) xxx
10) xxx
11) xxx
12) xxx
13) xxx
15) xxx
16) xxx

Altar 1) xxx
17) - 20 Road) xxx
20 Plaza) fields are on lower slope of hill.
21 Balcourt) xxx
22 Road) xxx
23) -27) xxx
28) Probable human long bone in side 5.
29)-31) xxx
32) Extremely rocky field
33) Site undifferentiated from fields where it is located.
34) In fallow field sandy soil w/humus.
35) Field surrounding mound is very rocky, hasn't been cleared recently.
36) Fields fallow and used for grazing.

37) Site is terraced cornfield.

38)-42) xxx

43) Previous cultivation in plaza, now used for grazing.

44) Isolated by heavy mesquite, cactus, and brush. Borders on cornfield.

45)-48) xxx

49) Sherd scatter in cornfield

50)-51) xxx

52) Top of mound is part of adjacent plaza - wall of terrace falls toward the river.

53) Field used for grazing, remains of irrigation ditch.

53 Plaza) Previously cultivated and irrigated, now follow and grazed.

54)-57 Plaza) xxx

58)-73B) xxx

Additional Data Sheet for Variable 37

Sites

1) -13) xxx

15) 8 mesquite, 1 napel cactus, 2 canoe plus corn.

16) Agricultural field.

17)-28) xxx

29) River 50 yards.

30) River 100 yards.

31)-45) xxx

46) Water 200'.

47)-49) xxx

50) River less than 100 yds.

51) River 100 yds.

52) On river.

53) River yields gravel 500 yds.

53 Plaza) River for irrigation close.

54)-73B) xxx

Appendix B

Calculations of Tabulations

There are three methods used for calculating the tabulations: 1) a graph which depicted individual site characteristics, 2) a simple chart totaling the characteristics for all sites or for a given site group,[5] 3) in three cases, variables 34, 51, and 52, a chart was made. A high and a low point were ascertained. For the calculation of the middle point and a description of the high and low points for each variable, see below.

Variable 34 asks for the compositions of rock types for each site. In each case, the recorder marked all of the rock types found at each site and of those rocks marked, the percentage that each contributes to the total composition of each site. A chart was made to determine the total number of appearances each rock made per site group. Then these totals, for each rock, were combined to determine the total for all sites. Next charted was 1) the highest percentage of each rock type for all 73 sites, 2) the lowest percentage of each rock type for all 73 sites, and 3) the average of all percentages recorded for each rock type.

Variable 54 asks for the distances of each site from several obstacles (e.g. river, hill, mountain). For each site, it was recorded whether the obstacle was "on" or "near" a site. A chart was made to determine the number of "on" and "near" sites, per site group, per obstacle. Next, a chart was made which showed per site group for each obstacle, the lowest recorded distance, the highest recorded distance, and the distance which occurred most of the points in between. This results in three trends: 1) the highest recorded distance for each obstacle (this is the distance from a given obstacle to the furthest site within a given site group), 2) the lowest recorded distance for each obstacle, and 3) all the points in between occurring 4 or more times. If, of all the middle points, a given distance didn't occur 4 or more times and the recordings were scattered, no middle trend was given. It was decided that a trend could only be valid if it contained 4 or more of the same recorded distance. The assumption of validity is that if a number occurs in more than fifty percent of the cases examined, then a trend exists. If each site group contains 15 sites and four to five of them are included in determining the high and low trends, then 4 or more is roughly 50 percent of the remaining sites.

---

[5] There are five site groups, none of which contain more than 18 sites. The grouping of sites was arbitrary. Group 1) included sites 1-14, 2) sites 15-22, 3) sites 23-35, 4) sites 36-57p, 5) sites 58-73B. The site-composition of each site group varies for certain variables, see calculation charts.

Variable 1

Distance of nearest trail in yards

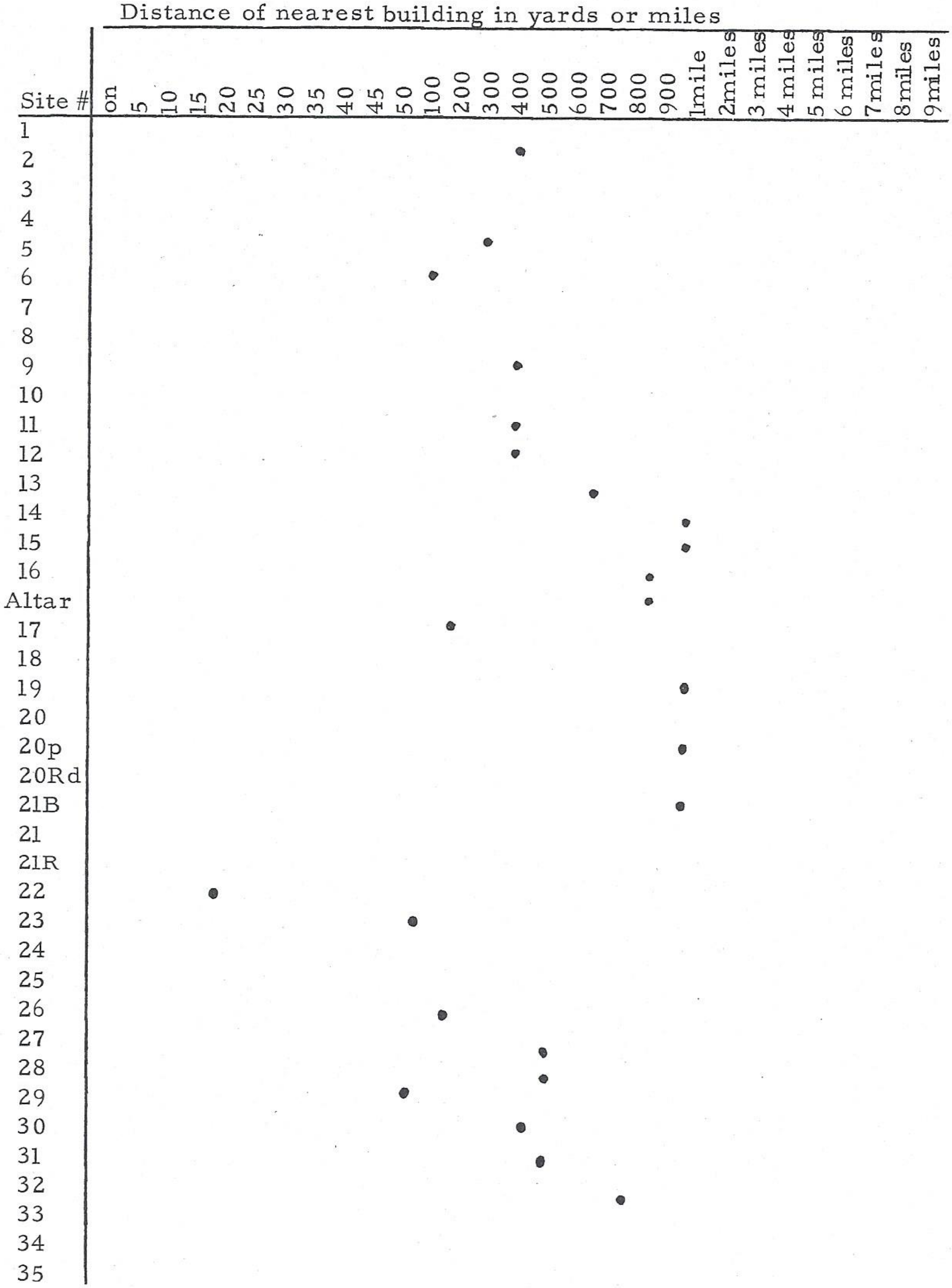
Site #	on	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	150	200	300	400	500	600	700	800	900	1000
1							●																								
2													●																		
3							●																								
4							●																								
5													●																		
6																															
7																					●										
8																															
9	●																														
10																															
11								●																							
12							●																								
13	●																														
14																					●										
15																					●										
16													●																		
Altar	None																														
17	None																														
18	●																														
19	●																														
20	●																														
20 p																										●					
20Rd																															
21B																										●					
21																															
21 Rd																															
22																															
23																															
24																															
25	●																														
26	●																														
27	●																														
28	●																														
29	●																														
30	●																														
31																								●							
32																								●							
33																								●							
34																															
35																															

Variable 1 continued

Distance of nearest trail in yards

Site #	on	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	150	200	300	400	500	600	700	800	900	1000
36																															
37																									●						
38											●																				
39																															
40																															
41																															
42	●																														
43	●																														
44-73B	were not recorded																														

Variable 2


Distance of nearest building in yards or miles
Site #
on
5
10
15
20
25
30
35
40
45
50
100
200
300
400
500
600
700
800
900
1mile
2miles
3 miles
4 miles
5 miles
6 miles
7miles
8miles
9miles
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Altar
17
18
19
20
20p
20Rd
21B
21
21R
22
23
24
25
26
27
28
29
30
31
32
33
34
35

Variable 2 continued

Distance of nearest building in yards or miles

Site #	on	5	10	15	20	25	30	35	40	45	50	100	200	300	400	500	600	700	800	900	1 mi	2 mi	3 mi	4 mi	5 mi	6 mi	7 mi
36																											
37																					●						
38																											
39																					●						
40																					●						
41																					●						
42																											
43																											
44			Not recorded until 69																								
45																											
46																											
47																											
48																											
49																											
50																											
51																											
52																											
53																											
54																											
55																											
56																											
57																											
58																											
59																											
60																											
61																											
62																											
63																											
64																											
65																											
66																											
67																											
68																											
69												●															
70																											
71																											
72																											
73A																											
73B																											

Variable 3

No. of site from which nearest site is recorded	No. of nearest site	Distance in yards of the nearest site																							
		0	5	10	15	20	25	30	35	40	45	50	55	100	125	150	200	300	400	500	600	700	800	900	1000
1	2		●																						
2	1		●																						
3	2														●										
4	-																								
5	?																		●						
6	?														●										
7	1																	●							
8	?																	●							
9	10, 11, 12													●											
10	-																								
11	8						●																		
12	10						●																		
13	?														●										
14	15														●										
15	14, 16											●													
16	14						●																		
Altar	16														●										
17	18			●																					
18	17			●																					
19	20, 21, 22								●																
20	19					●																			
20p	21													●											
20Rd.	-																								
21B	-																								
21	21B													●											
21Rd	20p				●																				
22	-																								
23	24						●																		
24	23						●																		
25	22																			●					
26	25					●																			
27	28			●																					
28	27			●																					
29	26									●															
30	28									●															
31	-																								
32	-																								
33	32																●								
34	35									●															
35	24, 33															●									

Variable 3 continued

No. of site from which nearest site is recorded	No. of nearest site	Distance in yards of the nearest site																							
		0	5	10	15	20	25	30	35	40	45	50	55	100	125	150	200	300	400	500	600	700	800	900	1000
36	35															●									
37	36																	●							
38	36																		●						
39	37																			●					
40	39								●																
41	40												●												
42	41								●																
43	26, 29														●										
44	42														●										
45	43													●											
46	43							●																	
47	64									●															
48	-																								
49	-																								
50	43,46,51, 54													●											
51	-																								
52	53		●																						
53	52		●																						
53p	53		●																						
54	52		●																						
55	-																								
56	-																								
57	-																								
57p	27, 28	●																							
58	-																								
59	57, 57p, 58							●																	
60	-																								
61	60, 59	●																							
62	-																								
63	-																								
64	47							●																	
65	-																								
66	65							●																	
67	71															●									
68	67					●																			
69	-																								
71	-																								
73A	67, 68													●											
73B	73										●														

Calculation Charts

Variable 4: 100% C

Variable 5:

Site groups:	E	A	P	O
1-14	4	9	6	1
15-21	3	3	3	0
22-35	8	7	5	2
36-54	11	11	5	2
55-73B	8	18	1	0
Total (all sites)	34	48	20	5

Variable 7:

Site groups:	A	B	C	D	E	F	G	J
1-14	13			8		1	8	2
15-21	5		2	2			2	6
22-35	11		1	3	1			2
36-54	11		1	9	1		6	1
55-73B	9			12				
Total (all sites)	39	0	4	34	2	1	16	11

Variable 8:

Site groups:	A	B	C	D
1-14		6	6	
15-21	1	8	2	
22-35	2	6	5	
36-54	2	7	9	
55-73B			8	
Total (all sites)	5	27	30	0

Variable 10:

Site groups:	A	B	C
1-14		3	11
15-21	1	7	2
22-35		5	11
36-54			16
55-73B			8
Total (all sites)	1	15	48

Variable 11: site 25 = 1 dwelling

Variable 12: 100% B

Calculation charts continued

Variable 13:		A	B	C	D	A	B	C	A	B	C	D
Site groups:	1-14		4	7	5	1	8	5	4	1	5	
	15-21		3	2	7	7	1	1	2		3	
	22-35	1	5	6		4	2	4	3		6	
	36-54	1	8	9	5	4		4	1		4	
	55-73B		8	12	5	5						
Totals		2	28	36	22	21	11	14	10	1	18	0

Variable 14:		A	B	C	D	E	A	B	C
Site groups:	1-14	2	6	4	2		2	5	5
	15-21	1	3	3	3		3	2	1
	22-35	4	6	4			4	3	3
	36-54	1	5	10	6		4	1	4
	55-73B		2	12	11		4		
Totals		8	22	33	22	0	17	11	13

Variable 15: 100% D (no perishables)

Variable 16: wall on sites: 2, 8, 13, 16, 22, 29, 30, 36, 43
drain on site: 15
road on site: 20

Variable 17:		A	B	C	D	E
Site groups:	1-14			3	1	1
	15-21		1	1	4	1
	22-35				4	
	36-54				8	
Totals		0	1	4	17	2

Variable 18:		A	B	C	D	E	F
Site groups:	15-21		1				
	22-35	3	1	2		1	
Totals		3	2	2	0	1	0

Variable 19: 1 piece of negative painted pottery in site group 1

Calculation charts continued

Variable 20:	no. of appearances A	B	C	D	E	F	G	amount at each appear. A	B	C	D	E	F	G
Site groups: 1-14	9	1				1	1	17	1				1	1
15-21	2						2	3						2
22-35	1	2	1	1		1		2	2	1	1		1	
36-54	6	1		1	1	3		11	1		1	1	12	
55-73B	5	1		1				5	1		1			
Totals	23	4	1	3	1	4	3	38	4	1	3	1	14	3

Variable 21:	A	B	C	D
blades			4	1
scrapers		1	1	3
cores		1	1	3
chips		1	4	
flakes			2	1
Totals	0	3	12	8

Variable 22:	A	B	C	D
blades		1	3	1
scrapers		1	3	
cores			2	2
chips			4	
flakes			4	
Totals	0	2	16	3

Variable 23:	A	B	C	D
blades				3
scrapers				3
cores				3
chips				3
flakes				3
Totals	0	0	0	15

Variable 24:	A	B	C	D
blades			1	3
scrapers			1	3
cores			1	3
chips			1	3
flakes			1	3
Totals	0	0	5	15

Calculation charts continued

Variable 25:	A	B	C	D	E
pre-classic	1			3	
classic	1	2			1
post-classic	1				
Totals	3	2	0	3	1

Variable 26: Only four trails = irrigation and grazing, 2 unknown

---

Variable 27:

Agriculture	A	B	C	D	E
evidence of	9	64			
irrigation	17	24	2	15	
patterning	3	11	25	8	
% arable land	7	6	4	15	30

Variable 29:

Soil types	A	B	C	D	E	F	G
Site groups: 1-14	1	2			12		
15-21				6	4		
22-35	2		1	2	4		
36-54	1	2			8	1	
55-73B	3	2			5	1	
Totals	8	6	1	8	43	2	0

Variable 31:

Erosion	A	B	C	D
Site groups: 1-14	1	1	10	
15-21	1	8	2	
22-35	1	10	2	
36-54		5	14	1
55-73B			12	1
Totals	3	24	40	2

Variable 32:	A	B	C	D	E
water drainage	41	17	12		
distance	46	15	2	0	
type	0	4	42	0	4

1 permanent, 15 intermittant

Calculation charts continued

Variable 33:	A	B	C	D	E	F	G
topography	50	19	13	0	0	0	0
exposure	2	41	6	10	0	0	0
slope	41	9	4	1	1	0	0

Variable 34:	sandst	shale	limest	conglo	o. sed.	slate	schist	marble	qrtzit	coal	o. meta	lava	basalt	granit	quartz	o. ign.	no out	0 depth	1/2 m "	1m "	2m+	chert
Site groups:																						
1-14			1	3	1				3				13	8			7					
15-22	1		3	7					3		3		8	9	3	1	6		1	3		
23-35				6	1				3				5	8	1	1	4			2		
36-57p				2					2				9	10	1	7	10					2
58-73B													5				9				4	
Total appearance, all sites	1	0	4	18	2	0	0	0	11	0	3	0	40	35	5	9	36	0	1	5	4	2
average all sites	10			19					25				51	36	30	26						

Variable 36:*	% major type					density				
Site groups:	A	B	C	D	E	A	B	C	D	E
1-14		1						1	1	1
15-22										1
23-35			2	1						
36-57p	3	1	2	1	2	1	1	2	4	10
58-73B					5				1	12
Totals	3	2	2	1	7	1	1	3	6	24

Variable 51a	on only					near only				
Site groups:	R	H	M	RG	A	R	H	M	RG	A
1-14					1	12	12	8	5	4
15-22		7		7		8	5	3	2	1
23-35		2				13	16		1	
36-57p	8					3	5			
58-73B	2				1	10				

---

* The ecotype for all sites is succulent desert.

Calculation charts continued

Variable 51b:

	Site groups:					
	1 - 14	15 - 22	23-35	36-57p	58-73B	
river	50	50	36	0	50	low
river	400		200	100	150	mid
river	800	1 mi	2 mi	200	300	high
hill	800	0	0	200		low
hill	1200	80		300		mid
hill	1600	800	800	400		high
mountain	400	0				low
mountain		1.5 mi				mid
mountain		1 mile				high
rugged	20	0				low
rugged	400	100	100			mid
rugged	800	120				high
arroyo	1				0	low
arroyo	20	250		60		mid
arroyo	60					high

Variable 52:

Site groups:	low	mid	high
1-14	0	4	5
15-22	0	2	3
23-35	0	3	9
36-57p	0	0	9
58-73B	0	1	5

REFERENCE

Zubrow, E.B.W. 1972. National Science Foundation Grant Proposal for Guanajuato Project. Stanford University.

A GROWTH MODEL OF SUBSISTENCE CULTURES

Keith Kintigh

Theoretical Background

In this section, the theoretical basis for the model proposed by this paper is explained and explored. Although the description of Schumpeter's model is incomplete, the fundamental points are presented.[1]

It should be kept in mind that several different models are discussed in this paper. First, Schumpeter's model, then an adaption of it, and finally and explicit simulation are discussed.

Schumpeter's Model of Unstable Economic Growth

Schumpeter's model of economic development is a model which views the process of development as driven by innovation, with a resultant growth pattern which is not uniform. The innovation-expansion-(growth)-equilibrium cycle operates as follows:

The model starts with many firms in perfect competition, with the economy in equilibrium. Equilibrium, the stable condition, here means primarily that profits are zero. Furthermore, it means that the marginal utility of additional investment, with the current technology, is also zero.

Now, for reasons presented later, let us assume that a technological innovation is introduced. Acceptance of the innovation will require construction, since the innovation requires new investment for implementation. New construction will be undertaken: first, because of expectation of monopoly profits in the utilization of the innovation, and because of increased marginal efficiency of capital; second, because old production centers will become obsolete; and third, because the innovation may cause an increased propensity to consume, so consumers will dip into their savings, and demand will increase.

Schumpeter claims that after the first firms utilize the innovation, the remainder of the firms will follow in clusters. The industry will gradually retool, with a resultant higher investment level. As the relevant industry and related industries near total acceptance of the innovation, the rate of new investment will decrease to a maintenance level. As the supply increases, prices fall, debts are paid off and a new equilibrium is reached at a new technology/investment level.

Schumpeter further argues that innovations will occur in stable conditions for two reasons. First, the pressure to innovate is largest at equilibrium, (perhaps because people's desire to engage in additional activity to produce growth is greatest when no activity to this end is being executed or the role of science at equilibrium differs from its role in a time of crisis or instability). Second, the risk of innovating is at a minimum (as the marginal efficiency of capital is nil).

---

[1] Information used in this paper concerning Schumpeter's model was obtained mainly from Higgins, 1968.

Higgins (1968) presents a set of pseudoformal relations concerning variables in the model. These relations are summarized in Fig. 1. In this diagram, an arrow indicates an unspecified functional dependency. (a) ⇒ (b) indicates that "b" is dependent on "a".

Reformulation of Schumpeter's Model

One thesis of this paper is that Schumpeter's unstable growth model can be reformulated to apply to subsistence, non-market economies in a meaningful way (Zubrow, 1973a).

First, as our unit of analysis, we will use the subsistence unit, and its environmental resource base. As our analog to the "perfect competition" assumption, we must assume that the system is closed.

In a market economy, money is a convenient measure of such entities as output, investment, and debt. In a non-market economy a different unit of measurement must be found to evaluate these entities. We have chosen the concept of energy to accomplish this (Clark & Haswell, 1970).

Output, or production, is the quantity of consumeable energy produced or gathered in some time period. If 1000 kg of wheat were produced in a year, this would represent an output of 3440 Kcal/year, as wheat contains roughly 3.440 Kcal per kg (Flannery, 1971). Growth, then, is a simple increase in output energy of the system under consideration.

For the purposes of this paper, investment is a quantity of human energy which has been expended to influence the capacity or productivity of an output unit. Therefore, cumulative labor going into the construction of an irrigation system, is considered to be investment, while energy going into annual production is not.

Savings for Schumpeter is different than investment. Savings will be considered to be a quantity of stored consumeable energy, that is, energy not tied up in investment. Schumpeter considers an innovation to be technological progress or resource discovery. Technology is here defined as the ratio of output energy to input energy of some productive system (e.g. if X Kcals are expended in hunting and Y Kcals of energy are obtained in meat, then the technology evidenced is Y/X, which is simply an efficiency). Hence, a technological innovation increases the output/input ratio.

The resource base is viewed as having an absolute limit of potential energy producing capacity. Of that, some fraction is considered

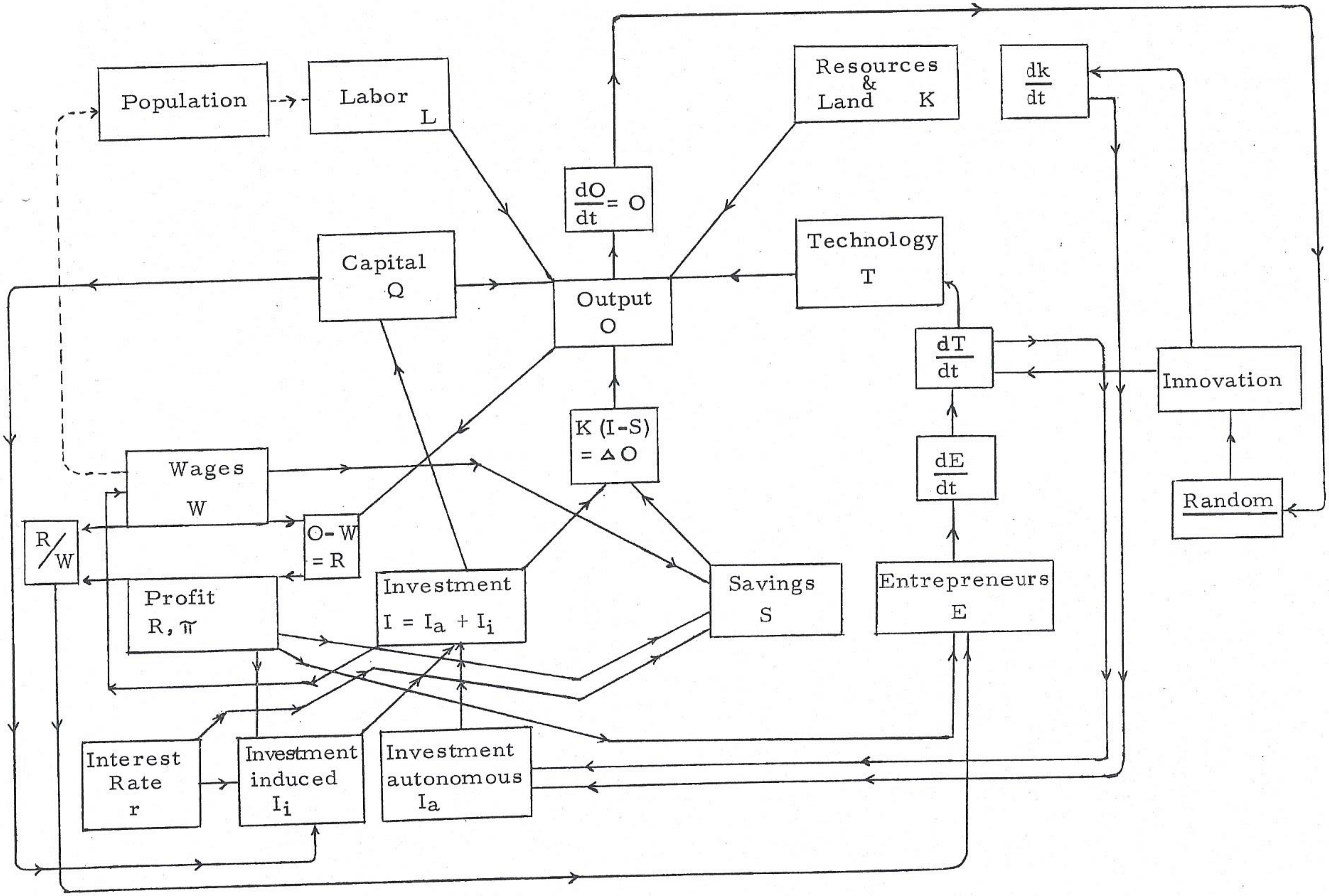


Figure 1. Schumpeter's Model of Unstable Growth

to be utilizable in the sense that it is known, and can be used at will. Therefore a resource discovery has the effect of increasing the fraction of energy potential which is usable.

To start the model, we have a subsistence unit in equilibrium with its environment. All production is consumed, yet no one starves. There is no advantage at this time to increased investment, as the current technology is fully realized for the labor force.

Now, we propose, an innovation occurs. We assume that the innovation will require an investment in order to be realized. The subsistence group will dip into existing savings to finance the investment in expectation of higher production.

As the fraction of the labor force using the innovation produces a surplus (relative to the old technology), this surplus may be invested in the technology until the technology is fully implemented.

If a group strives to maintain a certain level of savings for use in times of adversity or in readiness for an innovation, the lack of this level of savings may be considered a debt. The magnitude of the debt, then, is the difference between the level of savings desired by the group and the current level of savings.

Production in excess of that required for the subsistence of the group and the maintenance of the desired savings may be considered surplus. ("Surplus" is used in a slightly different sense in the simulation.)

As a technology nears full implementation, there will be production which is not directly consumed, and not invested. This will go into repayment of the debt or into additional savings.

If the population increases to consume this surplus, or if the surplus is otherwise consumed, the unit will eventually reach an equilibrium state,like that initially specified.

This process description is summarized in Fig. 2.

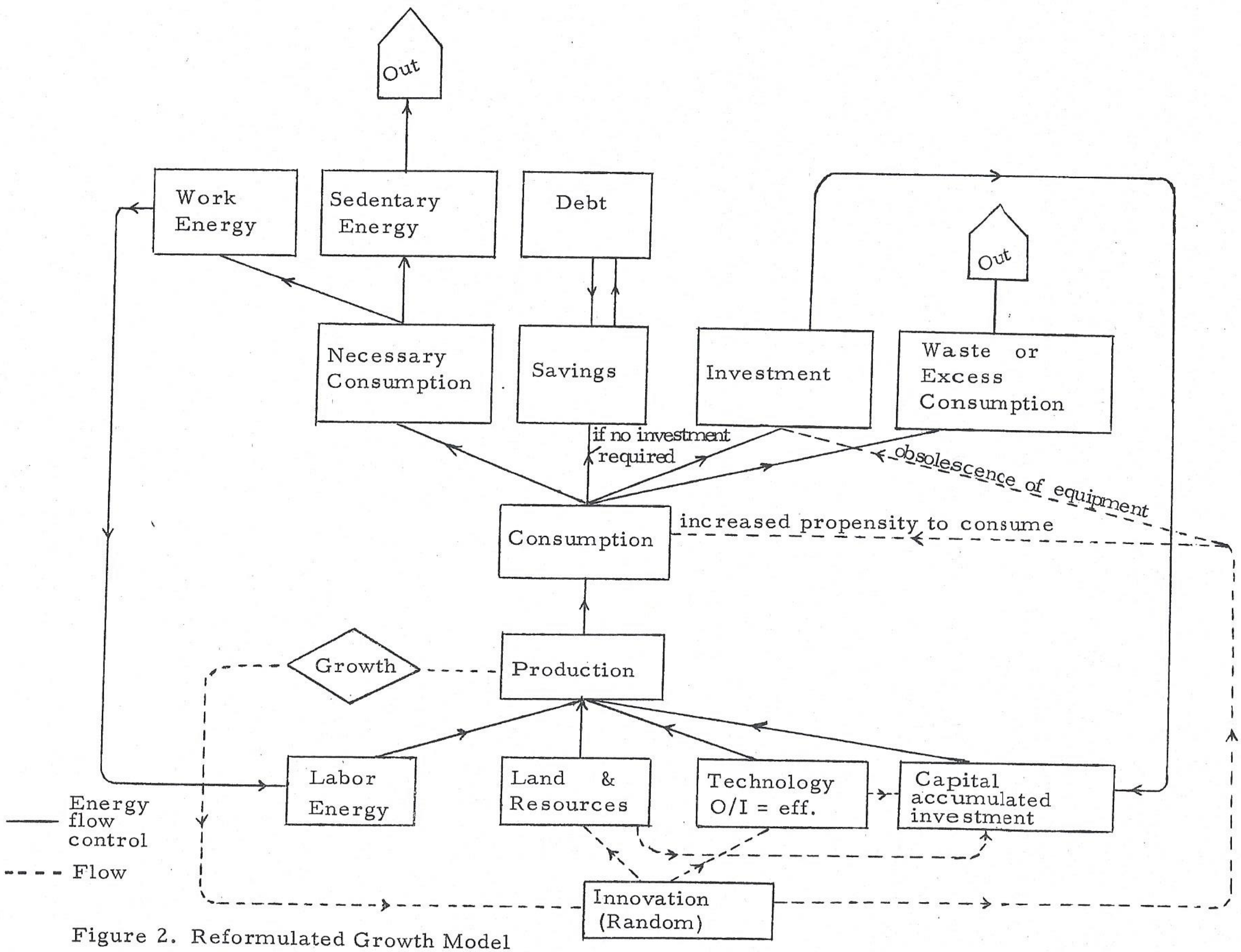


Figure 2. Reformulated Growth Model

Heuristic Example

To enable the reader to get a better feeling for this model, a simplistic example of its operation in a hypothetical subsistence unit is presented below.

Let us suppose that we have an island populated by one subsistence unit in one ecological zone. This zone is being entirely utilized in the production of one food crop at the highest level of technology available. This situation has resulted in a stable population.

An inventive native hypothesizes that irrigating the fields would increase crop production (i.e. resource utilization). He digs his ditches and produces crops from his irrigated fields. To the amazement of his neighbors, his production is 25 percent better per unit area.

Gradually others decide to implement this innovation. For some this requires going into debt, since in order to use this innovation, one must invest significant time in digging irrigation ditches before any production is realized. On the individual level, the debt may be in the form of an obligation, to those who helped him in his construction. After a given individual finishes his initial investment, and crops are produced, he must repay his debts with his excess production. His repayment enables others to invest in the innovation.

On a less direct level, other segments of the social structure must adapt to irrigation. A selective set of craftsmen, specializing in sluice gates, may appear, or roads may require rerouting, around irrigation ditches.

Eventually most producers will adopt irrigation, and their debts will be paid off. At this point we are at a new equilibrium, with a higher output, and a higher level of investment.

The Simulation Model

In this section a simulation of the reformulation of Schumpeter's model is described. First there is a general discussion of the nature of the process of the transformation of Schumpeter's model, through an intermediate step, to a final simulation and test. Then the operation of the model is discussed, along with the assumptions of the model. Finally, the behavior of the simulation model is described.

Thus far two "models" have been discussed, Schumpeter's and its reformulation. Schumpeter's model is highly intuitive but utterly untestable. One can conceive of testable implications of Schumpter's model[2] (Zubrow, 1973a: II-29 ff). However, even to test these implications one must make a large number of assumptions. In addition it is clear that a test of these implications cannot validate Schumpeter, since the operation of the model is not adequately specified.[3]

---

[2] E.g. innovations will occur in times of economic stability.

The second model presented above was an attempt to partially remedy the underspecification and to introduce the reader to concepts of the simulation. This second model was elaborated to form the final simulation model. The simulation model is formally described in Appendix A in an algorithmic language, ALGOL W. The ALGOL description is, in effect, a description of the model to an ignorant computer. This language has the advantages of logical precision and reasonable readability.

In addition to being a formal description of the model it is a computer program for the simulation model. This has two immediate consequences. First, if the model has inadequate assumptions built in, the simulation will not run. Put in another way, we know the output produced is exactly a product of the model including its assumptions (Dutton & Starbuck, 1971: 4). Secondly, we can run the simulation and see how the model behaves with different inputs.

Operation

This description of the operation of the model will, as much as possible, follow the structure of the formal description given in Appendix A, and use similar terminology. The description presented below demonstrates the central features and assumptions of the model. However, it neglects details. The ALGOL description was written with readability in mind and should be consulted for detailed information.

(Names in capital letters refer either to variable names or procedure (subroutine) names in the computer model.)

INITIALIZE. Assume the initial state of the economy to be stable and initialize variables accordingly. This means that as long as technology remains the same, production, population, savings and investment should all stay constant. Several initial variable conditions are input by the user (e.g. RESOURCE_POTENTIAL – absolute energy potential of the resource base, HUMAN_SUBSISTENCE ENERGY – energy required for individual human subsistence). Others are computed (e.g. TECHNOLOGY - output/input ratio, RESOURCE_CAPACITY - energy of resource base available at the current technology). The result of this is that an equilibrium need not be calculated by the user of the model, but results from the input and calculated variable values.

---

[3] That is, Schumpeter deals with a large number of variables, let us say $x_1 . . . , x_n$. To say that $x_i = f(x_k . x_1 . . . , x_m)$; x_i is a function of $x_k, . . . , x_m$ is not adequate. To deal with a model we must know the operation of f, the function. Even to say that x_i is an increasing function of x_j is not sufficient. If we know $x_1 = f(x_2)$; $x_3 = f(x_4)$; x_2 incr $\Rightarrow$ x_1 incr; x_4 incr $\Rightarrow x_3$ decr, we may want to know what happens to $x_1 + x_3$ if x_2 and x_4 are increased by one unit.

PRODUCE. Using LABOR_ENERGY - the energy expended by the population for production, the INVESTMENT_ LEVEL in each technology level, the RESOURCE_CAPACITY, and the TECHNOLOGY available, compute the OUTPUT for this time period. The INVESTMENT_LEVEL (TECH_LEVEL) is the fraction of the RESOURCE_CAPACITY which has been improved up to the technology level indicated by TECH_LEVEL. That is, an innovation will at times be incompletely implemented, because the necessary investment has not been made to utilize the innovation. An innovation produces a new maximum TECH_LEVEL.

Computing the OUTPUT happens as follows: at the top level of technology available (CUR_TECH_LEVEL) the production at this technological level equals LABOR (TECH_LEVEL)*TECHNOLOGY. LABOR represents the amount of labor energy available which can be used at this TECH_LEVEL to utilize all of the RESOURCE_CAPACITY which has been improved to this TECH_LEVEL.

At the next lower TECH_LEVEL the same procedure is executed, utilizing only the remaining RESOURCE_CAPACITY and LABOR_ENERGY.

OUTPUT is then the sum of production at each TECH_LEVEL going down until all labor energy is utilized, or all the RESOURCE_CAPACITY used.

INNOVATE. Production in the last two time periods is examined. If there has been less than a set percentage growth (STABILITY) then with a set probability (PROPENSITY_TO_INNOVATE) an innovation will occur. If the subsistence unit is completely utilizing the current RESOURCE_CAPACITY, then the innovation will be in the form of a RESOURCE_EXPANSION, otherwise it will be a TECHNOLOGICAL_INNOVATION (see the section on the reformulation of Schumpeter's model for explanation). This last assumption is made since, in each case, the innovation the unit receives is the only one it can use to increase production.[4] Either process results in an increase of the CUR_TECH_LEVEL.

---

[4] If the subsistence unit is operating at the resource capacity, then all of the utilizable energy is being drawn from the environment, and although an increase of efficiency would allow a decreased labor force it could not increase production. Likewise, an increase in capacity alone cannot increase production unless production already utilizes the entire resource capacity.

TECHNOLOGICAL_INNOVATION. A technological innovation is an increase of TECHNOLOGY, the output/input ratio. This increase is for lack of anything better a RANDOM fraction of a maximum increase in technology (MAX_TECH_INNOV).

RESOURCE_EXPANSION. A resource expansion is an increase in RESOURCE_UTILIZ, the usable fraction of the RESOURCE_POTENTIAL. This increase is a RANDOM fraction of a maximum increase (MAX_RES_EXPANSION). For obvious reasons RESOURCE_UTILIZ cannot exceed 1.

As an important assumption, both of the above innovation processes will require an increased level of investment per output unit (INVEST_PER_RES). To explain this, a digression to further explain investment is required.

There is an initial investment per output unit required for production. For example if the base investment is 1, this implies that for each unit of output the resource base supplies, there must have been one unit of labor invested at some time. An increase in technology requires an added investment to the base investment. For example, if technology level 1 has a required investment of 1, level 2 may require an additional .1 and level 3 an additional .15. Hence, to make unimproved land useful at the third technology level, 1 + .1 + .15 = 1.25 units per output unit investment are required.

For lack of a better procedure, the size of the increment to the investment is a function of the percent increase in TECHNOLOGY or in RESOURCE_UTILIZ and a constant factor, CAPITAL_INCR_FACTOR. This factor relates the strength of the innovation to incremental investment. (We are using CAPITAL_INCR_FACTOR = 1.5).

ADJUST_POPULATION controls BIRTHS, DEATHS, and STARVATIONS. BIRTHRATE is determined differently depending on whether GROWTH exceeds STAGNANT. If the economy is growing, the BIRTHRATE approaches a limit. The change in BIRTHRATE is based on the amount of SURPLUS in this time period. (SURPLUS = OUTPUT - NECESSARY_CONSUMPTION) (NECESSARY_CONSUMPTION is the energy required to feed the POPULATION).

If the economy is STAGNANT (with growth less than a fixed percentage) then the BIRTHRATE depends in the same way upon SAVINGS rather than SURPLUS. In this case POPULATION tends to a size that allows a minimum SAVINGS_LIMIT to be maintained. (see reformulation of Schumpeter's model)

DEATHRATE in this model is constant. STARVATIONS are in addition to DEATHS produced by the DEATHRATE. If in a time period, NECESSARY_CONSUMPTION cannot be met from OUTPUT + SAVINGS, then the number of people who cannot be fed, starve. The model assumes that children starve first.

This routine also adjusts the LABOR_POOL. Individuals enter the LABORPOOL at a fixed MATURE_AGE and leave it at OLDAGE.

CONSUME_INVEST. OUTPUT in this model goes 4 places. First OUTPUT is used to feed the POPULATION. Next the remainder of OUTPUT and accumulated SAVINGS are invested, so far as that is useful. The remainder, up to a limit (MAX_SAVINGS)[5] is saved and the rest is somehow consumed or wasted.

The amount going into INVESTMENT is that amount which, when made, allows the maximum proportion of the LABOR_POOL to use the TECHNOLOGY and RESOURCE_UTILIZ of the CUR_TECH_LEVEL. As explained above, in order to do this, INVESTMENT must be made at all lower levels, to be used at the top level. Hence INVESTMENT is made in order from the bottom level up to CUR_TECH_LEVEL.

Behavior

The simulation described in the section on operation (and Appendix A) has been run a number of times. In the remainder of this subsection, the general behavior of the model will be discussed, and the reaction of the model to changes in different input parameters examined.

The simulation has a large number of input parameters (20). Tests to determine behavior were done by taking a standard set of initializations, and varying one parameter and comparing outputs.

In preparation for a test of the model, research was done to determine the input parameters for the test case at hand (Hay Hollow Valley, Arizona 100-1300 A.D.). The values used as standard input parameters came from the data discovered in preparing the test. (A discussion of this data is presented in the Data). These standard input parameters are given along with a short description on pages 6-8 of Appendix A. Note that the time interval chosen represents one year.

Hence the tests run were for a range of variables subjectively considered to be reasonable.

Six variables were considered central in the analysis of this simulation. They are output, population, labor pool, starvations, investment, and savings. A typical set of results is given in Appendix B. (Beware of the scale on the graphed output, similar graphs may differ in scale). In discussing variables affecting other variables, one must be aware of the fact that very many of them are interdependent.

---

[5] This is done on the assumption that energy stored as food, decays over time, and can only be saved in limited quantities.

Output is characterized by cycles of stability followed by approximately exponential growth leveling off at a higher stable output level. The growth is a response to an innovation.

The time lag required for the innovation to significantly affect the output, is affected by the amount of investment required for the innovation to be used, (small investment ⇒ rapid response), the savings on hand which can go into investment (large saving ⇒ rapid response) and the magnitude of the innovation (large innovation ⇒ rapid response) (however, large innovation ⇒ large investment).

The rate of growth is affected by a number of factors. An increase in maximum birthrate will increase growth rate, however, this can cause later instability in the output; a decrease in the maximum savings which can be maintained, seems to increase the growth rate (probably by way of interaction with the population adjustor). Increasing the length of time workers stay in the work force also increases the growth rate. The factor by which investment is increased with a technology increase has very little effect on the growth rate. Changing the initial investment level or minimum savings level has a similarly small effect. As would be expected, the greater the innovation, the larger the growth rate.

Growth levels off to a new level of stability either when the output reaches the resource capacity, or when all available labor used at the top level of technology can just supply the population with subsistence energy (whichever occurs first).

An elaboration of this point may be in order here. In the initial state, a fixed proportion of the population, the labor force, is exactly able to produce for the entire population. What a technological innovation does, is provide temporary overhead necessary to expand production. That is, in the initial state, any birth, over and above deaths, would starve. Since new births do not enter the labor pool for perhaps 10 years, they do not increase the production, only the consumption. However, by hypothesis, in the initial stable state all production is consumed by the population and there is no surplus.

Population, in the first analysis, grows as output grows, with a significant time lag. (In these experiments 12-43 years), but instead of leveling off, settles into a cyclic unstable equilibrium. Like output, population exhibits an exponential growth. The cyclic variation is a product of delay in entering the labor pool of new births and the constant interaction between birthrate and output. This cyclic phenomenon was not forseen. With variable combinations that make for unstable output, the variation in population may be so great that a stable population level is found well below a peak population carrying capacity.

Direct population variables, e.g. birthrate, deathrate, have the expected effects on population. By the nature of the population adjustment function any increased output growth rate will result in increased population growth.

The labor pool grows much as population does, with the time lag introduced by the fact that individuals cannot enter the labor pool immediately after birth. What is perhaps surprising, is that even though population may cyclically vary 15 - 20 percent, the labor pool may remain constant, or may vary even more while maintaining a constant output. (The latter implies surpuls labor).

Starvations seem mainly affected by the rapidity of change in population as discussed above. Because of this, increasing the savings limit may increase starvations in the long run, since savings influence birthrate, and savings will cycle with excess production.

Investment varies much as expected. It does not tend to cycle and always reaches 0 sufficiently long after an innovation, since there is a limited investment to be made at each technology increase. As mentioned above, increases in the factor of capital investment for resource expansion and technological innovation only serve to retard production somewhat, and raise the level of investment at each time period.

Savings, in general, grows smoothly along with the last leg of output growth. As population cycles, savings cycles, offset by 180 degrees. That is, low populations imply high savings. As population increases, it uses the savings. The savings drop to zero and some of the population starves. The birthrate is meanwhile decreasing and savings again grow.

Most of the surprising action and instability occur by way of the constant delayed feedback between population and output. These fluctuations represent serious problems in the proposed model, as the degree of instability produced seems intuitively quite unlikely.

Validation of the Simulation Model

The simulation model presented, claims to explain and predict long term economic growth, mainly by reference to technology. The purpose of a validation is to determine how good a predictive tool the model is. In this section we do not attempt to present conclusive evidence. Rather, this section attempts to provide a view of what a validation of the model would look like, and secondly to present what data has been collected which bears on the question of validity.

Validation Procedure

One strategy for validating a simulation model is to use it as a black box to predict known data, given other known, related data. Thus, if we can tell the simulation, the situation at time t, and it can reliably predict the state of its universe in later time periods without further input, then it has succeeded. In a given empirical situation the simulation needs certain information as input. If the model is true, it should generate further information concerning the situation at hand which fits the data. It should be noted that there may be any number of different black boxes which will produce the same output from the input given. If however, one uses the black box on a variety of empirical situations and receives good fit, one gains confidence in the model.[6]

A better strategy, which is really only an elaboration of the first, would be to dissect the model and test its components, then reassemble them and test the unit. This strategy then puts the black box problem at the component level, rather than at the complete simulation level.[7] For the simulation model of this paper, one might then want to take the population adjustment function and deal with it separately. It could be tested and improved. Then the other segments could be tested and the improved model (the combination of the improved segments) could be tested. If the fit with data was not good, and one had confidence in the subprocesses, one might then know to look for problems in the relations between the subprocess, not in the processes themselves. In the first strategy one may have no idea where to look to solve problems that arise.

Nevertheless, presented below is an instance of the first strategy.

Data

The simulation model, which is the subject of this paper, takes as input several initial conditions concerning physical/biological constants and social structural variables, generates random innovations and produces, among other things, a prediction of population and output.

In this section, we wish to take an empirical example, find the inputs and compare the predictions with the actual data. However, in addition to the required inputs we wish to provide the simulation with information concerning actual innovations.[8]

---

[6] There exist statistical techniques to quantify some of these judgments, but they will not be discussed here.

[7] One can, of course, separate the model into any number of subassemblies and components, and test at each level. However, with limited time, knowledge, and resources this repeated subdivision rapidly becomes infeasible.

[8] In this simulation we do not claim to have any model of the generation of innovation. It is characterized as a random process, for lack of any better alternative. Even if innovation is in some sense random, there is no reason to believe that our random number generator is the same as nature's (God's).

As the reader may have guessed, the data required to test this model over a long time period, say 1000 years, is not readily available. The best job possible has been done within time constraints to collect as good data as possible for this validation.

The empirical situation chosen is the Hay Hollow Valley, Arizona, from A.D. 100 to A.D. 1300. This area has been extensively studied by archaeologists directed by Dr. Paul S. Martin of the Field Museum of Natural History. In the time period under consideration, it appears that the population grew from about 100 to about 2500. In this period the economy went from primary dependence on hunting and gathering to an irrigated agricultural system. The area considered is roughly 18.5 square miles.

Below are presented the data collected to initiate this validation.

1. Environmental Variables

a. Resource potential. This may be thought of as the maximum energy production possible for the area. The resource potential is the sum of the resource potential in each of six ecological zones. The resource potential of an ecological zone is defined to be the product of the annual productivity per unit area, the energy per unit biomass, and the area. Productivity and energy per unit biomass come from Zubrow (1971b: 200-201). Area figures are also from Zubrow (1971a: 133).

Resource Zone	Area mi^2	Productivity gm biomass/mo	Kcal/ gm biomass	Months	Potential 10^6 cal
1	1.17	10.08	4	4	$5.25*10^5$
2	2.15	12.4	4	4	$1.11*10^6$
3	.92	14.66	4	4	$5.50*10^5$
4	1.43	7.18	4	4	$4.28*10^5$
5	2.84	2.14	4	4	$2.49*10^5$
7	9.92	22.70	4	4	$9.93*10^6$
Totals	18.43				$12.20*10^6$

Figure 3. Resource Productivity of the Hay Hollow Valley

2. Population Data

a. Population. (There are a number of problems with this data discussed by Schiffer (1968:4-21) and Zubrow (1971b:150-151.) Population at a given time is estimated by the total number of habitation rooms used in that period times an estimate of the number of people/habitation room. The valley has been surveyed several times and an estimate of habitation rooms per time period is given by Zubrow (1973b). (The sites are mainly pottery dated by Dr. Paul Martin.) The number of inhabitants per room is a matter of some controversy but we will use the estimate given in Zubrow (1969:40).

Time	Number of Rooms	Occupants/room	Population
100-200	22 1/2	5.13	115
200-300	35	5.13	179
300-400	37 1/2	5.13	193
400-500	70	5.13	359
500-600	85	5.13	436
600-700	110	5.13	565
700-800	80	5.13	410
800-900	157 1/2	5.13	805
900-1000	357 1/2	5.13	1830
1000-1100	412 1/2	5.13	2115
1100-1200	430 1/2	5.13	2209
1200-1300	497 1/2	5.13	2558

Figure 4. Population of the Hay Hollow Valley

b. The fraction of mature individuals in the labor pool is estimated at 1/2. This assumes there is a strict male/female division of labor for work on energy production. This assumption is based on Pueblo ethnographic literature (e.g. Dozier, 1966).

c. Dozier (1966) implies that Hopi boys start to go to the fields with their fathers at age 7 or 8. Based on this we will set 10 as the age for productively entering the work force.

d. The average age at which a worker leaves the work force is estimated to be 42.

e. The maximum birthrate allowable will be set at 3 1/3 percent which is within the bounds of birthrates of developing countries.

f. We estimate initial birth and deathrate to be 2 percent. This assumption is noncrucial, in that birthrate easily adjusts.

3. Human Energy Variables

a. Sedentary energy, the average energy used in sedentary activity by an individual in a 24 hour day, is set at 2000 Kcal/day (Clark: 1970: 17).

b. Worker output energy, the energy expended in active work (above sedentary energy) is set at 170 Kcal/hr (Clark, 1970: 17).

c. The hours worked per day is estimated at 4, in consideration of the arguments of Clark et al. (1970:15) and the short agricultural season of perhaps 4 months.

4. Technology, Investment and Savings

a. The fraction of a crop which, at most, can be saved is set arbitrarily at 1/3.

b. The minimum savings is arbitrarily 5 percent of the last output.

c. The level of growth deemed stagnant is .1 percent.

d. We assume that investment per output unit in hunting and gathering is small, i.e. 1. Clark (1970:39) indicates it may require 200 man hours/hectare to clear Danish farmland with primitive tools. If a square meter of land yields 91.29 Kcal (Zubrow, 1971b), and if an hour of work represents 170 Kcals, we get an investment per output unit of

$$\frac{170 \text{ Kcal/hr} * 200 \text{ hr/hectare}}{91.29 \text{ Kcal/m}^2 * 10^4 \text{ m}^2 \text{ hectare} * .05} = \frac{34000}{45000} = .75$$

e. Technological changes. No figures could be found indicating increase in efficiency because of an innovation. There is evidence which suggests that the switch from hunting and gathering, to agriculture is not a very large one (Flannery, 1969; Zubrow, 1971: 202-203). We will assert that there is a 10 percent increase in efficiency. Irrigation, we will say, causes a 20 percent increase in efficiency.

f. Time of innovation. We will start the model in a hunting and gathering condition at A.D. 0 with negligible investment. The agricultural innovation will be available at A.D. 100 and the irrigation resource expansion at A.D. 1000 (McGregor, 1965: 272). These are both only rough estimates.

The values determined above are intended to be in the neighborhood of what empirically determined values would be. From the tests run on varying parameters, we have some reason to believe that small deviations in one or another may not seriously effect the operation of the model. It may well be, however, that the combined errors are sufficient to destroy the predictive power of the model. There was insufficient time and money available to determine a range of variation of parameters which yield roughly the same results.

Results

The simulation was run for 1300 time periods (57 seconds on Stanford's IBM 360/67). Output and population curves were generated from the input parameters specified in the last section.

Basically, at A.D. 0, the model was started at population 100 with a hunting and gathering economy. In the first stable period after A.D. 100, agriculture was introduced, with a 10 percent increase in technology. In the first stable period after A.D. 1000, irrigation was introduced as a resource expansion allowing 20 percent better utilization of the potential.

The results of this simulation are given in Appendix B. The only prediction which can be checked directly is population at 100 year time intervals. The real data and the prediction are plotted in Figure 5.

I think overanalysis of these results would not be worthwhile. Assuming the data are correct, there are definite problems with the model. The population function is so important for output that the failure on population almost certainly implies failure in prediction of output.

Conclusion

Dealing with a theory in terms of a simulation forced two things. First, and most important, it forced the construction of a reasonably complete model. Having to link the model together sufficiently well that it operated in a remotely sensible fashion required directly dealing with many assumptions about the operation of economic and social systems. The close tie of the model to the data influenced the construction of the model in a way that made it more testable than it might otherwise have been.

The model presented in this paper was certainly not a spectacular success. From an optimist's standpoint, its major weakness seems to be its population regulating procedure. This procedure caused many problems in the debugging and use of the simulation. It yielded results which were intuitively problematic and which seemed oversensitive. With a more successful model of population growth it may be worthwhile to reexamine Schumpeter's ideas in the framework presented here.

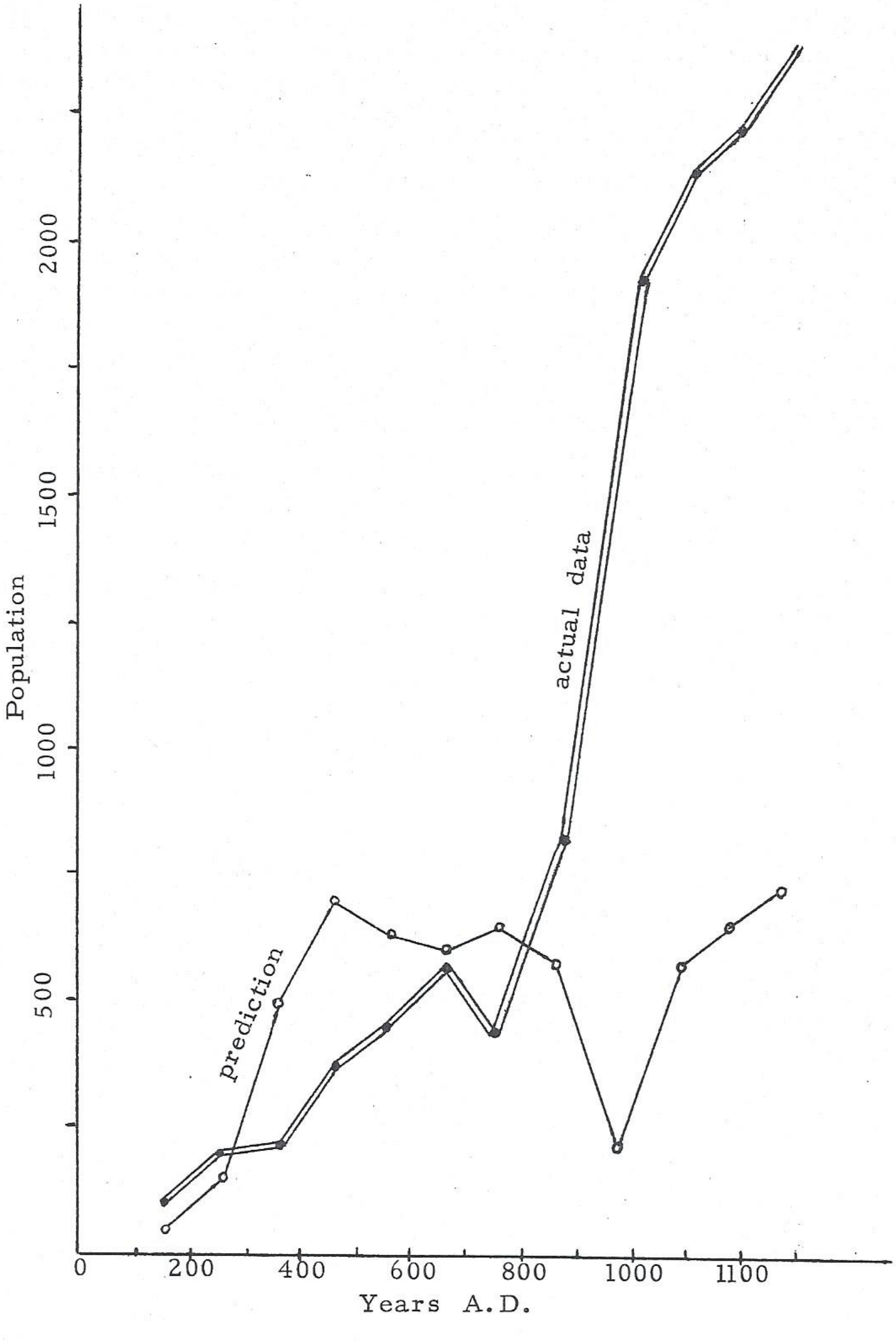


Figure 5. Predictions of the Model, and Empirical Data

On the other hand, the model may be just plain incorrect from a theoretical standpoint. Along this line, George Cowgill has provided some thought-provoking criticism (Cowgill; personal communication). He suggests first that such "developments" as the replacement of hunting and collecting by rainfall agriculture, and its replacement by irrigation may in face worsen the ratio of labor input to food output. Thus, these changes would not be accepted on a random, or automatic basis; rather the advantages or pressures which mitigate for the acceptance of such "developments" should be studied.

The foregoing discussion brings up more general points which concern some basic assumption's for this model. The model assumes first, an unrelenting tendency for economic growth, and second, a similar tendency for the population to increase to the point that the incremental population consumes the incremental production. The former is an element of Schumpeter's model, the latter, an element of this particular formalization of his model.

Finally, while a model of growth, not surprisingly, predicts growth, perhaps the cultural problem should be removed one level to ask the answer the "Why" as well as the "How" question of growth.

APPENDIX A

SIMULATION PROGRAM LISTING

```
STANFORD ALGOL W (25MAR73)         ECONOMIC GROWTH SIMULATION KWK        10 JUNE 1973 @ 15:57          PAGE  1

0000 1-      BEGIN
0001 --       INTEGER TIMELIMIT,MAX_TECH_LEVEL;
0002 --       LOGICAL PRINT;
0003 --       PRINT:=FALSE;
0004 --       TIMELIMIT:=200;
0005 --       MAX_TECH_LEVEL:=10;
0006 --
0006 2-         BEGIN
0007 --
0007 --      COMMENT +++++++++++++++++++++++++++;
0007 --      COMMENT +++++ I/O PROCEDURES +++++;
0007 --      COMMENT +++++++++++++++++++++++++++;
0007 --
0007 --      PROCEDURE CR_;
0008 --         IOCONTROL(2);
0009 --         COMMENT +++++ CARRAIGE RETURN - START NEXT LINE +++++;
0009 --
0009 --      PROCEDURE F_(REAL VALUE VAL;INTEGER VALUE INTLEN,FRACLEN);
0011 3-      BEGIN
0012 --         COMMENT +++++ PRINT A REAL NUMBER - F<INTLEN>.<FRACLEN> +++++;
0012 --         COMMENT +++++ INTLEN MUST INCLUDE 1 CHAR FOR SIGN +++++;
0012 --         INTEGER INT,FRAC;
0013 --         INT:=TRUNCATE(VAL);
0014 --         VAL:=VAL-INT;
0015 --         FRAC:=ABS(TRUNCATE(VAL*10**FRACLEN));
0016 --         I_(INT,INTLEN);
0017 --         WC_(".");
0018 --         IZ_(FRAC,FRACLEN);
0019 -3      END F_;
0020 --
0020 --      PROCEDURE GRAPH_WRT_TIME(INTEGER ARRAY VAL(*); STRING(20)VALUE TITLE);
0022 3-      BEGIN
0023 --         COMMENT +++++ FOR EACH TIME INTERVAL PLOTS TIME ON X-AXIS    +++++
0023 --                 +++++ AND VALUE ON THE Y-AXIS                       +++++;
0023 --         INTEGER MAX,MIN;
0024 --         COMMENT +++++ FIND MAX AND MIN OF VAL ARRAY +++++;
0024 4-         BEGIN
0025 --            MAX:=MIN:=VAL(0);
0026 --            FOR A:=1 UNTIL TIME_T DO
0026 --               IF VAL(A)<MIN THEN MIN:=VAL(A) ELSE IF VAL(A)>MAX THEN
0027 --                  MAX:=VAL(A);
0028 -4         END;
0029 --         COMMENT +++++ DRAW GRAPH +++++;
0029 4-         BEGIN
0030 --            INTEGER INCR;
0031 --            PF_;
0032 --            IOCONTROL(4);
0033 --            WL_("*");
0034 --            RC_("*",55);SK_(1);WRITEON(TITLE);SK_(1);RC_("*",55);
0039 --            WL_("*");
0040 --            LF_;
0041 --            SK_(6);
0042 --            INCR:=((MAX-MIN+1) DIV 126) +1;
0043 --            FOR A:=0 UNTIL 11 DO
0043 5-            BEGIN
0044 --               ILJ_(MIN+A*10*INCR,9);SK_(1);
0046 -5            END;
0047 --            CR_;
```

```
0048 --             SK_(6);
0049 --             FOR A:=0 UNTIL 11 DO
0049 5-             BEGIN
0050 --                WC_("|");SK_(9);
0052 -5             END;
0053 --             CR_;
0054 --             SK_(6);RC_("_",126);
0056 --             FOR A:=0 UNTIL TIME_T DO
0056 5-             BEGIN
0057 --               I_(A,4);SK_(1);WC_("|");SK_((VAL(A)-MIN) DIV INCR);WC_("*");CR_;
0063 -5             END;
0064 --             IOCONTROL(5);
0065 -4          END;
0066 -3       END GRAPH_WRT_TIME;
0067 --
0067 --       PROCEDURE I_(INTEGER VALUE VAL,INTLEN);
0068 3-       BEGIN
0069 --          COMMENT +++++ PRINT AN INTEGER _ I<INTLEN> +++++;
0069 --          COMMENT +++++ INTLEN MUST INCLUDE 1 CHAR FOR SIGN +++++;
0069 --          INTEGER A,LIMIT;
0070 --          STRING(14) INTSTR;
0071 --          LIMIT:=1;
0072 --          INTSTR:=" ";
0073 --          IF VAL<0 THEN
0073 4-          BEGIN
0074 --             INTSTR(0|2):="-0";
0075 --             LIMIT:=2;
0076 --             VAL:=ABS(VAL);
0077 -4          END;
0078 --          FOR A:=INTLEN STEP -1 UNTIL LIMIT DO
0078 4-          BEGIN
0079 --             INTSTR(A|1):=CODE(240+(VAL REM 10));
0080 --             VAL:=VAL DIV 10;
0081 -4          END;
0082 --          A:=1;
0083 --          WHILE (A<=INTLEN-1) AND (INTSTR(A|1)="0") DO
0083 4-          BEGIN
0084 --             INTSTR(A|1):=INTSTR(A-1|1);
0085 --             INTSTR(A-1|1):=" ";
0086 --             A:=A+1;
0087 -4          END;
0088 --          IF VAL¬=0 THEN INTSTR(1|6):="*OVFL*";
0089 --          FOR A:=1 UNTIL INTLEN   DO WRITEON(INTSTR(A|1));
0090 -3       END I_;
0091 --
0091 --       PROCEDURE ILJ_(INTEGER VALUE VAL,INTLEN);
0092 3-       BEGIN
0093 --          COMMENT +++++ PRINT AN INTEGER _ I<INTLEN> +++++;
0093 --          COMMENT +++++ INTLEN MUST INCLUDE 1 CHAR FOR SIGN +++++;
0093 --          INTEGER A,LIMIT;
0094 --          STRING(21) INTSTR;
0095 --          LIMIT:=1;
0096 --          INTSTR:=" ";
0097 --          IF VAL<0 THEN
0097 4-          BEGIN
0098 --             INTSTR(0|2):="-0";
0099 --             LIMIT:=2;
0100 --             VAL:=ABS(VAL);
```

```
0101 -4           END;
0102 --           FOR A:=INTLEN STEP -1 UNTIL LIMIT DO
0102 4-           BEGIN
0103 --              INTSTR(A|1):=CODE(240+(VAL REM 10));
0104 --              VAL:=VAL DIV 10;
0105 -4           END;
0106 --           A:=1;
0107 --           WHILE (A<=INTLEN-1) AND (INTSTR(A|1)="0") DO
0107 4-           BEGIN
0108 --              INTSTR(A|1):=INTSTR(A-1|1);
0109 --              INTSTR(A-1|1):=" ";
0110 --              A:=A+1;
0111 -4           END;
0112 --           IF VAL¬=0 THEN INTSTR(1|6):="*OVFL*";
0113 --           FOR B:=0 UNTIL INTLEN-1 DO WRITEON(INTSTR(A+B|1));
0114 -3        END ILJ_;
0115 --
0115 --        PROCEDURE IZ_(INTEGER VALUE VAL,INTLEN);
0116 3-        BEGIN
0117 --           COMMENT +++++ PRINT AN INTEGER ¬ L.Z. - I<INTLEN> +++++;
0117 --           COMMENT +++++ INTLEN MUST INCLUDE 1 CHAR FOR SIGN +++++;
0117 --           INTEGER A,LIMIT;
0118 --           STRING(14) INTSTR;
0119 --           LIMIT:=1;
0120 --           INTSTR:=" ";
0121 --           IF VAL<0 THEN
0121 4-           BEGIN
0122 --              INTSTR(0|2):="-0";
0123 --              LIMIT:=2;
0124 --              VAL:=ABS(VAL);
0125 -4           END;
0126 --           FOR A:=INTLEN STEP -1 UNTIL LIMIT DO
0126 4-           BEGIN
0127 --              INTSTR(A|1):=CODE(240+(VAL REM 10));
0128 --              VAL:=VAL DIV 10;
0129 -4           END;
0130 --           A:=1;
0131 --           IF VAL¬=0 THEN INTSTR(1|6):="*OVFL*";
0132 --           FOR A:=1 UNTIL INTLEN   DO WRITEON(INTSTR(A|1));
0133 -3        END IZ_;
0134 --
0134 --        PROCEDURE LF_;
0135 3-        BEGIN
0136 --           COMMENT +++++ LINEFEED - SKIP 1 LINE +++++;
0136 --           WRITE(" ");CR_;
0138 -3        END;
0139 --
0139 --        INTEGER PROCEDURE MAX(INTEGER VALUE NUM1,NUM2);
0140 --           IF NUM1>NUM2 THEN NUM1 ELSE NUM2;
0142 --
0142 --        REAL PROCEDURE MAXR(REAL VALUE NUM1,NUM2);
0143 --           IF NUM1>NUM2 THEN NUM1 ELSE NUM2;
0145 --
0145 --        INTEGER PROCEDURE MIN(INTEGER VALUE NUM1,NUM2);
0146 --           IF NUM1<NUM2 THEN NUM1 ELSE NUM2;
0148 --
0148 --        REAL PROCEDURE MINR(REAL VALUE NUM1,NUM2);
0149 --           IF NUM1<NUM2 THEN NUM1 ELSE NUM2;
```

```
0151 --                                                                                   182.
0151 --     PROCEDURE PF_;                                                                183.
0152 --        IOCONTROL(3);                                                              184.
0153 --        COMMENT +++++ PAGEFEED - SKIP TO TOP OF A NEW PAGE +++++;                  185.
0153 --                                                                                   186.
0153 --     REAL PROCEDURE RANDOM;                                                        187.
0154 3-     BEGIN                                                                         188.
0155 --        COMMENT  THIS IS A UNIFORM RANDOM NUMBER GENERATOR WRITTEN BY G. E.        189.
0155 --          FORSYTHE IN SPRING 1969, FOLLOWING D. KNUTH, THE ART OF COMPUTER         190.
0155 --          PROGRAMMING, VOL. 2, PP. 155-156.  IT IS MUCH SUPERIOR TO RANDU,         191.
0155 --          THE RANDOM NUMBER GENERATOR FOUND IN IBM'S SCIENTIFIC SUBROUTINE         192.
0155 --          PACKAGE;                                                                 193.
0155 --        REFERENCE (EXCEPTION) RESTORE;                                             194.
0156 --        RESTORE := INTOVFL;                                                        195.
0157 --        INTOVFL := NULL ;                                                          196.
0158 --        QQ := QQ*314159269 + 453806245 ;                                           197.
0159 --        IF QQ < 0 THEN QQ :=(QQ + 2147483647)+ 1 ;                                 198.
0160 --        COMMENT THAT CORRECTS FOR AN OVERFLOW OF QQ TO A NEGATIVE INTEGER          199.
0160 --          BY ADDING 2**31.  THUS MAIN IS EXECUTED MODULO 2**31;                    200.
0160 4-        BEGIN                                                                      201.
0161 --           UNIF := QQ ;                                                            202.
0162 --           UNIF := UNIF * 0.465661287307739'-9;                                    203.
0163 -4        END ;                                                                      204.
0164 --        INTOVFL  := RESTORE ;                                                      205.
0165 --        UNIF                                                                       206.
0165 -3     END RANDOM;                                                                   207.
0166 --                                                                                   208.
0166 --     PROCEDURE RC_(STRING(1) VALUE STR; INTEGER VALUE LEN);                        209.
0168 --        FOR A:=1 UNTIL LEN DO WC_(STR);                                            210.
0169 --        COMMENT +++++ PRINT  A REPEATED CHARACTER - <LEN>(1H<STR>) +++++;          211.
0169 --                                                                                   212.
0169 --     PROCEDURE SK_(INTEGER VALUE LEN);                                             213.
0170 --        RC_(" ",LEN);                                                              214.
0171 --        COMMENT +++++ SKIP SPACES - <LEN>X +++++;                                  215.
0171 --                                                                                   215.5
0171 --     REAL PROCEDURE SUM(REAL ARRAY ARRAY1(*);INTEGER VALUE NUM);                   215.6
0173 --        IF NUM=0 THEN 0 ELSE ARRAY1(NUM)+SUM(ARRAY1(*),NUM-1);                     215.7
0175 --                                                                                   216.
0175 --     PROCEDURE WC_(STRING(1) VALUE  STR);                                          217.
0176 --        WRITEON(STR);                                                              218.
0177 --        COMMENT +++++ PRINT 1 CHARACTER - 1H<STR> +++++;                           219.
0177 --                                                                                   220.
0177 --     PROCEDURE WL_(STRING(1) VALUE STR);                                           221.
0178 3-     BEGIN                                                                         222.
0179 --        COMMENT +++++ WRITE A LINE OF A CHARACTER - 132(1H<STR>)                   223.
0179 --        CR_;                                                                       224.
0179 --        RC_(STR,132);                                                              225.
0180 -3     END;                                                                          226.
0181 --                                                                                   227.
0181 --                                                                                   228.
0181 --     COMMENT +++++++++++++++++++++++++++++++++++;                                  229.
0181 --     COMMENT +++++ SIMULATION PROCEDURES +++++;                                    230.
0181 --     COMMENT +++++++++++++++++++++++++++++++++++;                                  231.
0181 --                                                                                   232.
0181 --                                                                                   233.
0181 --     PROCEDURE ADJUST_POPULATION;                                                  234.
0182 3-     BEGIN                                                                         235.
0183 --        REAL AVERAGE;                                                              236.
```

```
STANFORD ALGOL W (25MAR73)               ECONOMIC GROWTH SIMULATION KWK        10 JUNE 1973 @ 15:57          PAGE  5
0184 --        INTEGER STARVED,TIME,TEM;                                                   237.
0185 --        COMMENT +++++ ADJUST BIRTHRATE +++++;                                       238.
0185 --           COMMENT +++++ BIRTHRATE MOVES S.T.POP CONSUMES ALL OUTPUT +++++          239.
0185 --                   +++++ BUT MAINTAINS A LIMITED SAVINGS            +++++;          240.
0185 --           IF GROWTH>STAGNANT THEN                                                  241.
0185 4-           BEGIN                                                                    242.
0186 --              ADJUSTMENT(TIME_T):=((SURPLUS(TIME_T-1)-SAVINGS_LIMIT)/               243.
0186 --                 (HUMAN_SUBSISTENCE_ENERGY*POPULATION(TIME_T-1)));                  244.
0187 --              IF ADJUSTMENT(TIME_T)>=0 THEN                                         244.5
0187 --                 ADJUSTMENT(TIME_T):=MINR(1,SQRT(ADJUSTMENT(TIME_T)))               245.
0187 --              ELSE ADJUSTMENT(TIME_T):=MAXR(-1,-SQRT(-ADJUSTMENT(TIME_T)));         245.1
0189 --              BIRTHRATE(TIME_T):=BIRTHRATE(TIME_T-1) +                              246.
0189 --                 ADJUSTMENT(TIME_T)*(MAX_BIRTHRATE - BIRTHRATE(TIME_T-1));          247.
0190 -4           END ELSE                                                                 248.
0191 4-           BEGIN                                                                    249.
0192 --              ADJUSTMENT(TIME_T):=((SAVINGS(TIME_T-1)-SAVINGS_LIMIT)/               250.
0192 --                 (HUMAN_SUBSISTENCE_ENERGY*POPULATION(TIME_T-1)));                  251.
0193 --              IF ADJUSTMENT(TIME_T)>0 THEN                                          253.
0193 5-              BEGIN                                                                 253.5
0194 --                 ADJUSTMENT(TIME_T):=MINR(1,SQRT(ADJUSTMENT(TIME_T)));              253.6
0195 --                 BIRTHRATE(TIME_T):=BIRTHRATE(TIME_T-1) +                           254.
0195 --                    ADJUSTMENT(TIME_T)*(MAX_BIRTHRATE - BIRTHRATE(TIME_T-1));       255.
0196 -5              END ELSE                                                              255.5
0197 5-              BEGIN                                                                 255.6
0198 --                 ADJUSTMENT(TIME_T):=MAXR(-1,-SQRT(-ADJUSTMENT(TIME_T)));           255.7
0199 --                 BIRTHRATE(TIME_T):=BIRTHRATE(TIME_T-1) +                           256.
0199 --                    ADJUSTMENT(TIME_T)*(BIRTHRATE(TIME_T-1)-0);                     257.
0200 -5              END;                                                                  257.5
0201 -4           END;                                                                     258.
0202 --           DEATHRATE(TIME_T):=DEATHRATE(TIME_T-1);                                  259.
0203 --        COMMENT +++++ FIND BIRTHS & DEATHS +++++;                                   260.
0203 --           BIRTHS(TIME_T):=ROUND(BIRTHRATE(TIME_T)*POPULATION(TIME_T-1));           261.
0204 --           DEATHS(TIME_T):=ROUND(DEATHRATE(TIME_T)*POPULATION(TIME_T-1));           262.
0205 --           IF BIRTHRATE(TIME_T)>DEATHRATE(TIME_T) THEN
0205 --              BIRTHS(TIME_T):=MAX(BIRTHS(TIME_T),DEATHS(TIME_T)+1);
0206 --        COMMENT +++++ ADJUST POPULATION +++++;                                      263.
0206 --           POPULATION(TIME_T):=POPULATION(TIME_T-1)+BIRTHS(TIME_T)-                 264.
0206 --              DEATHS(TIME_T);                                                       265.
0207 --           STARVATIONS(TIME_T):=MAX(POPULATION(TIME_T)-(OUTPUT(TIME_T)              266.
0207 --              +SAVINGS(TIME_T-1)) DIV HUMAN_SUBSISTENCE_ENERGY,0);                  267.
0208 --           POPULATION(TIME_T)    :=POPULATION(TIME_T)-STARVATIONS(TIME_T);          268.
0209 --           STARVED:=STARVATIONS(TIME_T);                                            269.
0210 --           TIME:=TIME_T;                                                            270.
0211 --           WHILE (STARVED>0) AND (TIME>=(-OLDAGE-1)) DO                             271.
0211 4-           BEGIN                                                                    272.
0212 --              TEM:=MIN(BIRTHS(TIME),STARVED);                                       273.
0213 --              STARVED:=STARVED-TEM;                                                 274.
0214 --              BIRTHS(TIME):=BIRTHS(TIME)-TEM;                                       275.
0215 --              TIME:=TIME-1;                                                         276.
0216 -4           END;                                                                     277.
0217 --        COMMENT +++++ ADJUST LABOR POOL +++++;                                      278.
0217 --           LABOR_POOL(TIME_T):=ROUND(FRAC_WORKERS*(BIRTHS(TIME_T-MATURE_AGE)-       279.
0217 --              BIRTHS(TIME_T-OLDAGE)))+LABOR_POOL(TIME_T-1);                         280.
0218 --           LABOR_ENERGY(TIME_T):=LABOR_POOL(TIME_T)*WORKER_OUTPUT_ENERGY;           281.
0219 --        IF PRINT THEN                                                               282.
0219 --           WRITE("POPULATION      ",POPULATION(TIME_T));                            283.
0220 -3     END ADJUST_POPULATION;                                                         284.
0221 --                                                                                    285.
```

```
0221 --      PROCEDURE CONSUME_INVEST;                                                        286.
0222 3-      BEGIN                                                                            287.
0223 --         COMMENT +++++ CONSUME SUBSISTENCE ENERGY-SAVE,INVEST REMAINDER +++++;         288.
0223 --         INTEGER NECESSARY_CONSUMPTION;                                                289.
0224 --         NECESSARY_CONSUMPTION:=POPULATION(TIME_T)*HUMAN_SUBSISTENCE_ENERGY;           290.
0225 --         SURPLUS(TIME_T):=OUTPUT(TIME_T)+SAVINGS(TIME_T-1)-                            291.
0225 --            NECESSARY_CONSUMPTION;                                                     292.
0226 --         INVEST_SAVE;                                                                  293.
0227 -3      END CONSUME_INVEST;                                                              294.
0228 --                                                                                       295.
0228 --      PROCEDURE FINAL_OUTPUT;                                                          296.
0229 3-      BEGIN                                                                            297.
0230 --         COMMENT +++++ OUTPUT GRAPHS OF TIME CHANGE VARIABLES +++++;                   298.
0230 --         OUTPUT(0):=0;                                                                 299.
0231 --         GRAPH_WRT_TIME(OUTPUT(*),"------ OUTPUT ------");                             300.
0232 --         POPULATION(0):=0;                                                             301.
0233 --         GRAPH_WRT_TIME(POPULATION(*),"---- POPULATION ----");                         302.
0234 --         LABOR_POOL(0):=0;                                                             303.
0235 --         GRAPH_WRT_TIME(LABOR_POOL(*),"---- LABOR POOL ----");                         304.
0236 --         GRAPH_WRT_TIME(STARVATIONS(*),"--- STARVATIONS ----");                        304.1
0237 --         GRAPH_WRT_TIME(SURPLUS(*),"----- SURPLUS ------");                            305.
0238 --         GRAPH_WRT_TIME(INVESTMENT(*),"---- INVESTMENT ----");                         306.
0239 --         GRAPH_WRT_TIME(SAVINGS(*),"----- SAVINGS ------");                            307.
0240 -3      END FINAL_OUTPUT;                                                                308.
0241 --                                                                                       309.
0241 --      PROCEDURE INITIALIZE;                                                            310.
0242 3-      BEGIN                                                                            311.
0243 --                                                                                       311.5
0243 --      COMMENT +++++ INIT ALL VARIABLES TO BEGIN IN STABLE STATE +++++;                 313.
0243 --      COMMENT +++++ ENERGY  IS IN UNITS OF 10**6 CALS +++++;                           314.
0243 --                                                                                       314.5
0243 --      COMMENT ::: TIME_T = INTEGRAL  TIME PERIOD (YEAR):::;                            315.
0243 --         TIME_T:=0;                                                                    316.
0244 --                                                                                       316.5
0244 --      COMMENT ::: CUR_TECH_LEVEL = TECHNOLOGY LEVEL COUNTER:::;                        317.
0244 --         CUR_TECH_LEVEL:=1;                                                            318.
0245 --                                                                                       318.5
0245 --      COMMENT ::: POPULATION = POPULATION:::;                                          319.
0245 --         POPULATION(TIME_T):=50;                                                       320.
0246 --                                                                                       320.5
0246 --      COMMENT ::: FRAC_WORKERS = FRACTION OF MATURE POP IN LABOR POOL:::;              321.
0246 --         FRAC_WORKERS:=1/2;                                                            322.
0247 --                                                                                       322.5
0247 --      COMMENT ::: BIRTHRATE = BIRTH RATE , DEATHRATE = DEATHRATE :::;                  323.
0247 --         BIRTHRATE(TIME_T):=DEATHRATE(TIME_T):=.02;                                    324.
0248 --                                                                                       324.5
0248 --      COMMENT ::: MAX_BIRTHRATE = LARGEST BIRTH RATE POSSIBLE :::;                     325.
0248 --         MAX_BIRTHRATE:=.033;                                                          326.
0249 --                                                                                       326.5
0249 --      COMMENT ::: MATURE_AGE = AGE AT WHICH INDIVIDUAL JOINS LABOR POOL :::;           327.
0249 --         MATURE_AGE:=10;                                                               328.
0250 --      COMMENT ::: OLDAGE = AVERAGE AGE OF DEATH OR RETIREMENT :::;                     329.
0250 --         OLDAGE:=40;                                                                   330.
0251 --                                                                                       330.5
0251 --      COMMENT ::: DAY_YEAR = DAYS PER YEAR :::;                                        331.
0251 --         DAY_YEAR:=365;                                                                332.
0252 --                                                                                       332.5
0252 --      COMMENT ::: WORK_HR_DAY = AVERAGE HOURS OF WORK PER DAY :::;                     333.
```

```
0252 --         WORK_HR_DAY:=4;                                                 334.
0253 --                                                                         334.5
0253 --      COMMENT ::: WORKER_OUTPUT_ENERGY = ANNUAL WORK ENERGY PER WORKER :::;  335.
0253 --         WORKER_OUTPUT_ENERGY:=ROUND(.170*WORK_HR_DAY*DAY_YEAR);         336.
0254 --                                                                         336.5
0254 --      COMMENT ::: SEDENTARY_ENERGY = ANNUAL NONWORK ENERGY CONSUMED PER  337.
0254 --            INDIVIDUAL :::;                                              338.
0254 --         SEDENTARY_ENERGY:=ROUND(2.0*DAY_YEAR);                          339.
0255 --                                                                         339.5
0255 --      COMMENT ::: PROPENSITY_TO_INNOVATE = PROBABILITY OF AN INNOVATION  340.
0255 --            IN ANY EQUILIBRIUM YEAR :::;                                 341.
0255 --         PROPENSITY_TO_INNOVATE:=.02  ;                                  342.
0256 --                                                                         342.5
0256 --      COMMENT ::: STAGNANT = % GROWTH DEEMED EQUILIBRIUM :::;            345.
0256 --         STAGNANT:=.01;                                                  346.
0257 --                                                                         346.5
0257 --      COMMENT ::: CAPITAL_INCR_FACTOR = INVESTMENT INCREASE FACTOR REQ   347.
0257 --           OVER INNOVATION INCREASE FACTOR :::;                          348.
0257 --         CAPITAL_INCR_FACTOR:=1.5;                                       349.
0258 --                                                                         349.5
0258 --      COMMENT ::: MAX_TECH_INNOVATION = MAX FRAC OF TECH WHICH CAN BE    350.
0258 --            ADDED TO CURRENT TECH BY AN INNOVATION ::: ;                 351.
0258 --         MAX_TECH_INNOVATION:=.20;                                       352.
0259 --                                                                         352.5
0259 --      COMMENT ::: RESOURCE_UTILIZ = FRAC OF RESOURCE POTENTIAL WHICH CAN BE  353.
0259 --            CONVERTED TO USEFUL ENERGY BY POPULATION :::;                354.
0259 --         RESOURCE_UTILIZ(CUR_TECH_LEVEL):=.05;                           355.
0260 --                                                                         355.5
0260 --      COMMENT ::: MAX_RESOURCE_EXPANSION = MAX FRAC OF (1-RES UTILIZ)    356.
0260 --            WHICH CAN BE ADDED TO  CURRENT RES UTILIZ BY INNOV :::;      357.
0260 --         MAX_RESOURCE_EXPANSION:= .02;                                   358.
0261 --                                                                         358.5
0261 --      COMMENT ::: RESOURCE_POTENTIAL = ANNUAL ENERGY PROD OF POPULATION  359.
0261 --            AREA :::;                                                    360.
0261 --         RESOURCE_POTENTIAL:=12200000;                                   361.
0262 --                                                                         361.5
0262 --      COMMENT ::: INVEST_PER_RES = FRACTION OF RESOURCE CAP REQ AS       362.
0262 --            INVESTMENT FOR UTILIZ OF TECHNOLOGY LEVEL :::;               363.
0262 --         INVEST_PER_RES(CUR_TECH_LEVEL):=1;                              364.
0263 --                                                                         364.5
0263 --      COMMENT ::: QQ = NUMBER TO START RANDOM SEQUENCE :::;              365.
0263 --         QQ:=94305;                                                      366.
0264 --                                                                         366.5
0264 --      COMMENT ::: LABOR_POOL = # OF WORKERS IN POPULATION :::;           367.
0264 --         LABOR_POOL(TIME_T):=ROUND((OLDAGE-MATURE_AGE)/OLDAGE*FRAC_WORKERS*  368.
0264 --            POPULATION(TIME_T));                                         369.
0265 --                                                                         369.5
0265 --      COMMENT ::: BIRTHS = # OF BIRTHS AT TIME PERIOD :::;               370.
0265 --         FOR A:=(-OLDAGE-1) UNTIL 0  DO BIRTHS(A):=ROUND(POPULATION(TIME_T)*  371.
0265 --            BIRTHRATE(TIME_T));                                          372.
0266 --                                                                         372.5
0266 --      COMMENT ::: DEATHS = # OF DEATHS AT TIME PERIOD :::;               373.
0266 --         DEATHS(TIME_T):= ROUND(POPULATION(TIME_T)*DEATHRATE(TIME_T));   374.
0267 --                                                                         374.5
0267 --      COMMENT ::: HUMAN_SUBSISTENCE_ENERGY = ANNUAL ENERGY REQ PER       375.
0267 --            INDIVIDUAL :::;                                              376.
0267 --         HUMAN_SUBSISTENCE_ENERGY:=SEDENTARY_ENERGY+WORKER_OUTPUT_ENERGY;  377.
0268 --                                                                         377.5
```

```
0268 --      COMMENT ::: TECHNOLOGY = RATIO OUTPUT/INPUT ENERGY :::                       378.
0268 --         TECHNOLOGY(CUR_TECH_LEVEL):=(POPULATION(TIME_T)*                          379.
0268 --            HUMAN_SUBSISTENCE_ENERGY) / (LABOR_POOL(TIME_T)*                       380.
0268 --            WORKER_OUTPUT_ENERGY);                                                 381.
0269 --                                                                                   381.5
0269 --      COMMENT ::: RESOURCE_CAPACITY = USEABLE RESOURCE ENERGY AT CUR               382.
0269 --         UTILIZATION LEVEL :::                                                     383.
0269 --         RESOURCE_CAPACITY(CUR_TECH_LEVEL):=ROUND(RESOURCE_POTENTIAL*              384.
0269 --            RESOURCE_UTILIZ(CUR_TECH_LEVEL));                                      385.
0270 --                                                                                   385.5
0270 --      COMMENT ::: INVESTMENT_LEVEL = FRAC OF TOTAL RESOURCE AREA ON                386.
0270 --         WHICH INVESTMENT TO THIS TECH LEVEL HAS BEEN MADE :::                     387.
0270 --         INVESTMENT_LEVEL(CUR_TECH_LEVEL):=1;                                      388.
0271 --                                                                                   388.5
0271 --      COMMENT ::: LABOR_ENERGY = TOTAL ANNUAL LABOR ENERGY EXPENDED                389.
0271 --         BY THE POPULATION :::                                                     390.
0271 --         LABOR_ENERGY(TIME_T):=LABOR_POOL(TIME_T)*WORKER_OUTPUT_ENERGY;            391.
0272 --                                                                                   391.5
0272 --      COMMENT ::: INVESTED_ENERGY = TOTAL ENERGY INVESTED IN                       392.
0272 --         TECH LEVEL :::                                                            393.
0272 --         INVESTED_ENERGY(CUR_TECH_LEVEL):=MIN(ROUND(LABOR_ENERGY(TIME_T)*          394.
0272 --            TECHNOLOGY(CUR_TECH_LEVEL)*INVEST_PER_RES(CUR_TECH_LEVEL)),ROUND(      395.
0272 --            RESOURCE_CAPACITY(CUR_TECH_LEVEL)*INVEST_PER_RES(CUR_TECH_LEVEL)))     396.
0272 --            ;                                                                      397.
0273 --      COMMENT ::: OUTPUT = PRODUCED ENERGY IN TIME PERIOD :::                      398.
0273 --         OUTPUT(TIME_T):=ROUND(LABOR_ENERGY(TIME_T)*                               399.
0273 --            TECHNOLOGY(CUR_TECH_LEVEL));                                           400.
0274 --                                                                                   400.5
0274 --      COMMENT ::: MAX_SAVINGS_FRAC = PART OF OUTPUT WHICH MAY BE SAVED :::         400.6
0274 --         MAX_SAVINGS_FRAC:=.75;                                                    400.7
0275 --                                                                                   400.8
0275 --      COMMENT ::: SAVINGS_LIMIT = ENERGY RESERVE MAINTAINED BY POP :::             401.
0275 --         SAVINGS_LIMIT:=ROUND(OUTPUT(TIME_T)*.05);                                 402.
0276 --                                                                                   402.5
0276 --      COMMENT ::: SAVINGS = ACCUMULATED SAVED (NOT INVESTED) ENERGY :::            403.
0276 --         SAVINGS(TIME_T):=SAVINGS_LIMIT;                                           404.
0277 --                                                                                   404.5
0277 --      COMMENT ::: INVESTMENT = INVESTMENT MADE THIS TIME PERIOD :::                405.
0277 --         INVESTMENT(TIME_T):=0;                                                    406.
0278 --                                                                                   406.5
0278 --      COMMENT ::: STARVATIONS = # OF INDIVIDUALS WHO STARVED THIS                  407.
0278 --         TIME PERIOD :::                                                           408.
0278 --         STARVATIONS(TIME_T):=0;                                                   409.
0279 --                                                                                   409.5
0279 --      COMMENT ::: ADJUSTMENT = BIRTHRATE ADJUSTMENT FACTOR :::                     410.
0279 --         FOR A:=TIME_T-MATURE_AGE+1 UNTIL TIME_T DO                                411.
0279 --            ADJUSTMENT(A):=0;                                                      412.
0280 --                                                                                   412.5
0280 --      COMMENT ::: SURPLUS = PRODUCTION - SUBSISTENCE CONSUMPTION :::               413.
0280 --         SUPPLUS(TIME_T):=0;                                                       414.
0281 --                                                                                   414.5
0281 --         TIME_T:=1;                                                                415.
0282 --                                                                                   415.5
0282 -3      END INITIALIZE;                                                              416.
0283 --                                                                                   417.
0283 --      PROCEDURE INNOVATE;                                                          418.
0284 3-      BEGIN                                                                        419.
0285 --         COMMENT +++++ DECIDE IF AN INNOVATION OCCURS  THIS TIME PERIOD +++++      420.
```

```
0285 --              +++++ THEN DECIDE IF INNOVATION IS RESOURCE EXPANSION  +++++    421.
0285 --              +++++ INNOVATION OR TECHNOLOGICAL EFFICIENCY INNOVATION++++;    422.
0285 --         IF RANDOM<PROPENSITY_TO_INNOVATE THEN                                 423.
0285 4-         BEGIN                                                                 424.
0285 --            IF OUTPUT(TIME_T)=RESOURCE_CAPACITY(CUR_TECH_LEVEL) THEN           425.
0286 --               RESOURCE_EXPANSION  ELSE TECHNOLOGICAL_INNOVATION;              426.
0288 --         ~~IF AGRICULTURE THEN AGRICULTURE:=TRUE ELSE IRRIGATION:=TRUE;        426.1~~
0290 -4         END                                                                   427.
0290 -3      END INNOVATE;                                                            428.
0291 --                                                                               429.
0291 --      PROCEDURE INVEST_SAVE;                                                   440.
0292 3-      BEGIN                                                                    441.
0293 --         COMMENT +++++ ALLOCATE SURPLUS TO INVESTMENT AND SAVINGS +++++;       442.
0293 --         INVESTMENT(TIME_T):=INVEST_SURPLUS(SURPLUS(TIME_T),1);                443.
0294 --         SAVINGS(TIME_T):=MIN(MAX_SAVINGS,SURPLUS(TIME_T)-INVESTMENT(TIME_T)); 446.
0295 --         IF PRINT THEN                                                         447.
0295 4-         BEGIN                                                                 448.
0296 --            WRITE("INVESTMENT      ",INVESTMENT(TIME_T));                      449.
0297 --            WRITE("SAVINGS         ",SAVINGS(TIME_T));                         450.
0298 --            WRITE("INVESTMENT LEV ");                                          451.
0299 --               SK_(10);                                                        452.
0300 --               F_(INVESTMENT_LEVEL(CUR_TECH_LEVEL),1,2);                       453.
0301 -4         END;                                                                  454.
0302 -3      END INVEST_SAVE;                                                         455.
0303 --                                                                               456.
0303 --      INTEGER PROCEDURE INVEST_SURPLUS(INTEGER VALUE CURRENT_SURPLUS,          457.
0303 --         TECH_LEVEL);                                                          458.
0304 --      IF (CURRENT_SURPLUS<=0) OR (TECH_LEVEL>CUR_TECH_LEVEL) THEN 0 ELSE        459.
0305 3-      BEGIN                                                                    460.
0306 --         COMMENT +++++ INVEST SURPLUS AVAIL SUCH THAT THE ENTIRE +++++         461.
0306 --                 +++++ LABOR POOL CAN USE TOP TECHNOLOGY          +++++;       462.
0306 --         INTEGER MAX_USEABLE_INVEST,RESLT,DIFFERENCE;                          463.
0307 --         MAX_USEABLE_INVEST:=MIN(ROUND(LABOR_ENERGY(TIME_T)*TECHNOLOGY(        464.
0307 --            TECH_LEVEL)*INVEST_PER_RES(     TECH_LEVEL)),ROUND(                465.
0307 --            RESOURCE_CAPACITY(TECH_LEVEL)*INVEST_PER_RES(TECH_LEVEL)));        466.
0308 --         IF INVESTED_ENERGY(TECH_LEVEL)>=MAX_USEABLE_INVEST THEN RESLT:=0      467.
0308 4-            ELSE BEGIN                                                         468.
0310 --               DIFFERENCE:=CURRENT_SURPLUS-(MAX_USEABLE_INVEST-                469.
0310 --                  INVESTED_ENERGY(TECH_LEVEL));                                470.
0311 --               IF DIFFERENCE>=0 THEN RESLT:=CURRENT_SURPLUS-DIFFERENCE ELSE    471.
0312 --                  RESLT:=CURRENT_SURPLUS;                                      472.
0313 -4            END;                                                               473.
0314 --         INVESTED_ENERGY(TECH_LEVEL):=INVESTED_ENERGY(TECH_LEVEL) + RESLT;     474.
0315 --         INVESTMENT_LEVEL(TECH_LEVEL):=INVESTED_ENERGY(TECH_LEVEL)/            474.4
0315 --          (INVEST_PER_RES(TECH_LEVEL)*RESOURCE_CAPACITY(TECH_LEVEL));          474.5
0316 --         RESLT+INVEST_SURPLUS(CURRENT_SURPLUS-RESLT,TECH_LEVEL+1)              475.
0316 -3      END INVESTMENT;                                                          476.
0317 --                                                                               477.
0317 --      PROCEDURE PRINT_HEADING;                                                 477.01
0318 3-      BEGIN                                                                    477.02
0319 --         COMMENT +++++ PRINT TIME PERIOD HEADING +++++;                        477.03
0319 --         LF_;                                                                  477.04
0320 --         WL_("*");                                                             477.05
0321 --         RC_("*",58);WRITEON(" TIME PERIOD ");I_(TIME_T,3);SK_(1);RC_("*",57); 477.06
0326 --         WL_("*");                                                             477.07
0327 --         LF_;                                                                  477.08
0328 -3      END PRINT_HEADING;                                                       477.09
0329 --                                                                               477.1
```

```
0329 --      PROCEDURE PRODUCE;                                                          478.
0330 3-      BEGIN                                                                       479.
0331 --         COMMENT +++++ COMPUTE OUTPUT AND % GROWTH IN THIS TIME PERIOD +++++;     480.
0331 --         OUTPUT(TIME_T):=PRODUCTION(CUR_TECH_LEVEL,LABOR_ENERGY(TIME_T-1),1);     481.
0332 --         SAVINGS_LIMIT:=ROUND(OUTPUT(TIME_T)*.05);                                482.
0333 --         MAX_SAVINGS:=ROUND(MAX_SAVINGS_FRAC*OUTPUT(TIME_T));                     482.5
0334 --         GROWTH:=(OUTPUT(TIME_T)-OUTPUT(TIME_T-1))/OUTPUT(TIME_T-1);              483.
0335 --         IF PRINT THEN                                                            484.
0335 4-         BEGIN                                                                    485.
0336 --            WRITE("PRODUCTION      ",OUTPUT(TIME_T));                              486.
0337 --            WRITE("SAVINGS LIMIT   ",SAVINGS_LIMIT);                               487.
0338 -4         END;                                                                     488.
0339 -3      END PRODUCE;                                                                489.
0340 --                                                                                  490.
0340 --      INTEGER PROCEDURE PRODUCTION(INTEGER VALUE TECH_LEVEL,AVAIL_LABOR;REAL      491.
0341 --         VALUE UNUSED_RES_FRAC);                                                  491.5
0342 --      IF (TECH_LEVEL=0)  THEN 0 ELSE                                              492.
0343 3-      BEGIN                                                                       493.
0344 --         COMMENT +++++ COMPUTE PRODUCTION AT EACH TECH LEVEL RECURSIVELY+++++;    494.
0344 --         LABOR(TECH_LEVEL):=MIN(AVAIL_LABOR,ROUND((                               495.
0344 --            RESOURCE_CAPACITY(TECH_LEVEL)*MINR(INVESTMENT_LEVEL(TECH_LEVEL),      496.
0344 --            UNUSED_RES_FRAC))/TECHNOLOGY(TECH_LEVEL)));                           497.
0345 --         UNUSED_RES_FRAC:=UNUSED_RES_FRAC-(ROUND(TECHNOLOGY(TECH_LEVEL)*          497.1
0345 --            LABOR(TECH_LEVEL)))/RESOURCE_CAPACITY(TECH_LEVEL);                    497.2
0346 --         ROUND(TECHNOLOGY(TECH_LEVEL)*LABOR(TECH_LEVEL)+                          498.
0346 --            PRODUCTION(TECH_LEVEL-1,AVAIL_LABOR-LABOR(TECH_LEVEL),                499.
0346 --            UNUSED_RES_FRAC))                                                     499.1
0346 -3      END;                                                                        500.
0347 --                                                                                  501.
0347 --      PROCEDURE RESOURCE_EXPANSION;                                               502.
0348 3-      BEGIN                                                                       503.
0349 --         COMMENT +++++ INCREASE UTILIZEABLE RESOURCE CAPACITY-RATIO OF +++++      504.
0349 --                 +++++ UTILIZEABLE ENERGY TO ABSOLUTE MAXIMUM POTENTIAL+++++      505.
0349 --                 +++++ ENERGY OF THE ENVIRONMENT                       +++++;    506.
0349 --         REAL FACTOR;                                                             507.
0350 --         CUR_TECH_LEVEL:=CUR_TECH_LEVEL+1;                                        508.
0351 --         FACTOR:=(1-RESOURCE_UTILIZ(CUR_TECH_LEVEL-1))                            509.
0351 --            *MAX_RESOURCE_EXPANSION*RANDOM/RESOURCE_UTILIZ(CUR_TECH_LEVEL-1)      510.
0351 --            +1;                                                                   511.
0352 --         RESOURCE_UTILIZ(CUR_TECH_LEVEL):=RESOURCE_UTILIZ(                        512.
0352 --            CUR_TECH_LEVEL-1)*FACTOR;                                             513.
0353 --         RESOURCE_CAPACITY(CUR_TECH_LEVEL):=ROUND(RESOURCE_UTILIZ(                514.
0353 --            CUR_TECH_LEVEL   )*RESOURCE_POTENTIAL);                               515.
0354 --         IF ¬ PRINT THEN PRINT_HEADING;                                           516.
0355 --         WRITE("<< RESOURCE EXPANSION >> NEW UTILIZ ==> ");                       517.
0356 --            F_(RESOURCE_UTILIZ(CUR_TECH_LEVEL),1,3);                              518.
0357 --         INVEST_PER_RES(CUR_TECH_LEVEL):= (SUM(INVEST_PER_RES(*),                 519.
0357 --            CUR_TECH_LEVEL-1)*CAPITAL_INCR_FACTOR*(FACTOR-1));                    520.
0358 --         INVESTED_ENERGY(CUR_TECH_LEVEL):=0;                                      521.
0359 --         TECHNOLOGY(CUR_TECH_LEVEL):=TECHNOLOGY(CUR_TECH_LEVEL-1);                522.
0360 --         INVESTMENT_LEVEL(CUR_TECH_LEVEL):=0;
0361 -3      END RESOURCE_EXPANSION;                                                     523.
0362 --                                                                                  524.
0362 --      PROCEDURE TECHNOLOGICAL_INNOVATION;                                         525.
0363 3-      BEGIN                                                                       526.
0364 --         COMMENT +++++ INCREASE TECHNOLOGICAL LEVEL IF INCREASE THE +++++         527.
0364 --                 +++++ INPUT/OUTPUT EFFICIENCY RATIO FOR THE        +++++         528.
0364 --                 +++++ LEVEL OF RESOURCE CAPACITY AVAILABLE         +++++;        529.
```

```
0364 --        REAL FACTOR;                                                          530.
0365 --        CUR_TECH_LEVEL:=CUR_TECH_LEVEL+1;                                     531.
0366 --        FACTOR:=RANDOM*MAX_TECH_INNOVATION+1;                                 532.
0367 --        TECHNOLOGY(CUR_TECH_LEVEL):=TECHNOLOGY(CUR_TECH_LEVEL-1)*FACTOR;      533.
0368 --        IF ¬ PRINT THEN PRINT_HEADING;                                        534.
0369 --        WRITE("<< INNOVATION >> NEW LEVEL ==> ");                             535.
0370 --          F_(TECHNOLOGY(CUR_TECH_LEVEL),3,3);CR_;                             536.
0372 --        COMMENT +++++ COMPUTE THE NEW LEVEL OF INVESTMENT NECESSARY  +++++    537.
0372 --             +++++ PER          RESOURCE CAPACITY UNIT             +++++;   538.
0372 --        INVEST_PER_RES(CUR_TECH_LEVEL):= (SUM(INVEST_PER_RES(*),              539.
0372 --          CUR_TECH_LEVEL-1)*CAPITAL_INCR_FACTOR*(FACTOR-1));                  540.
0373 --        INVESTED_ENERGY(CUR_TECH_LEVEL):=0;                                   541.
0374 --        RESOURCE_CAPACITY(CUR_TECH_LEVEL):=RESOURCE_CAPACITY(CUR_TECH_LEVEL   542.
0374 --          -1);                                                                543.
0375 --        RESOURCE_UTILIZ(CUR_TECH_LEVEL):=RESOURCE_UTILIZ(CUR_TECH_LEVEL-1);   544.
0376 --        INVESTMENT_LEVEL(CUR_TECH_LEVEL):=0;
0377 -3      END TECHNOLOGICAL_INNOVATION;                                           545.
0378 --                                                                              546.
0378 --                                                                              547.
0378 --        COMMENT +++++++++++++++++++++++++++++++++++++++++++++++++;            548.
0378 --        COMMENT +++++ PRIMARY CONTROL SECTION OF SIMULATION +++++;            549.
0378 --        COMMENT ++++++++++++++++++++++(++++++++++++++++++++++++++;            550.
0378 --                                                                              551.
0378 --      COMMENT +++++ VARIABLE DECLARATIONS +++++;                              552.
0378 --        INTEGER MATURE_AGE,OLDAGE,TIME_T,HUMAN_SUBSISTENCE_ENERGY,            553.
0378 --          CUR_TECH_LEVEL,RESOURCE_POTENTIAL,WORKER_OUTPUT_ENERGY,QQ;          554.
0379 --        INTEGER SAVINGS_LIMIT,MAX_SAVINGS;                                    555.
0380 --        INTEGER SEDENTARY_ENERGY,DAY_YEAR,WORK_HR_DAY;                        556.
0381 --        REAL STAGNANT,MAX_RESOURCE_EXPANSION,MAX_TECH_INNOVATION,             557.
0381 --          CAPITAL_INCR_FACTOR,PROPENSITY_TO_INNOVATE,                         558.
0381 --          GROWTH,FRAC_WORKERS,UNIF,MAX_BIRTHRATE,MAX_SAVINGS_FRAC;            559.
0382 --        INTEGER ARRAY INVESTMENT,SAVINGS,SURPLUS,OUTPUT,DEATHS,STARVATIONS,   560.
0382 --          POPULATION,LABOR_POOL,LABOR_ENERGY (0::TIMELIMIT);                  561.
0383 --        INTEGER ARRAY BIRTHS (-60::TIMELIMIT);                                562.
0384 --        INTEGER ARRAY INVESTED_ENERGY,LABOR,                                  563.
0384 --        RESOURCE_CAPACITY(0::MAX_TECH_LEVEL)    ;                             564.
0385 --        REAL ARRAY BIRTHRATE,DEATHRATE (0::TIMELIMIT);                        565.
0386 --        REAL ARRAY ADJUSTMENT(-10::TIMELIMIT);                                566.
0387 --        REAL ARRAY INVESTMENT_LEVEL,TECHNOLOGY,RESOURCE_UTILIZ,               567.
0387 --          INVEST_PER_RES (0::MAX_TECH_LEVEL);                                 568.
0388 --                                                                              569.
0388 --        COMMENT +++++ INITIALIZE ALL VARIABLES TO A STABLE CONDITION  +++++;  570.
0388 --        INITIALIZE;                                                           571.
0389 --        WHILE TIME_T <= TIMELIMIT DO                                          572.
0389 3-        BEGIN                                                                 573.
0390 --                                                                              574.
0390 --          COMMENT +++++ PRINT TIME PERIOD HEADING +++++;                      575.
0390 --          IF PRINT THEN PRINT_HEADING;                                        576.
0391 --                                                                              577.
0391 --          COMMENT +++++ PRODUCE FOR THIS TIME PERIOD +++++;                   578.
0391 --          PRODUCE;                                                            579.
0392 --                                                                              580.
0392 --          COMMENT +++++ IF GROWTH IS STAGNANT-INNOVATION MAY OCCUR +++++;     581.
0392 --          IF GROWTH<=STAGNANT THEN INNOVATE;                                  582.
0393 --                                                                              583.
0393 --          COMMENT +++++ ADJUST POPULATION GROWTH +++++;                       584.
0393 --          ADJUST_POPULATION;                                                  585.
0394 --                                                                              586.
```

```
STANFORD ALGOL W (25MAR73)                ECONOMIC GROWTH SIMULATION KWK         10 JUNE 1973  @  15:57          PAGE  12

0394 --            COMMENT +++++ CONSUME AND INVEST THIS TIME PERIOD'S OUTPUT +++++;                    587.
0394 --            CONSUME_INVEST;                                                                      588.
0395 --                                                                                                 589.
0395 --            COMMENT +++++ END THIS TIME PERIOD +++++;;                                           590.
0396 --            TIME_T:=TIME_T+1;                                                                    591.
0397 --                                                                                                 592.
0397 -3         END;                                                                                   593.
0398 --                                                                                                 594.
0398 --         COMMENT +++++ PRINT FINAL OUTPUT +++++;                                                595.
0398 --         TIME_T:=TIME_T-1;                                                                      596.
0399 --         FINAL_OUTPUT;                                                                          597.
0400 --                                                                                                 598.
0400 --         COMMENT +++++ DUMP ARRAYS +++++;                                                       599.
0400 --         ICCONTROL(3);                                                                          600.
0401 --         TIMELIMIT:=(TIMELIMIT DIV 0);                                                          601.
0402 -2         END                                                                                    602.
0402 --                                                                                                 603.
0402 -1      END                                                                                       604.

EXECUTION OPTIONS: DEBUG,1  TIME=20 SECONDS PAGES=30 MARGIN=72
```

APPENDIX B

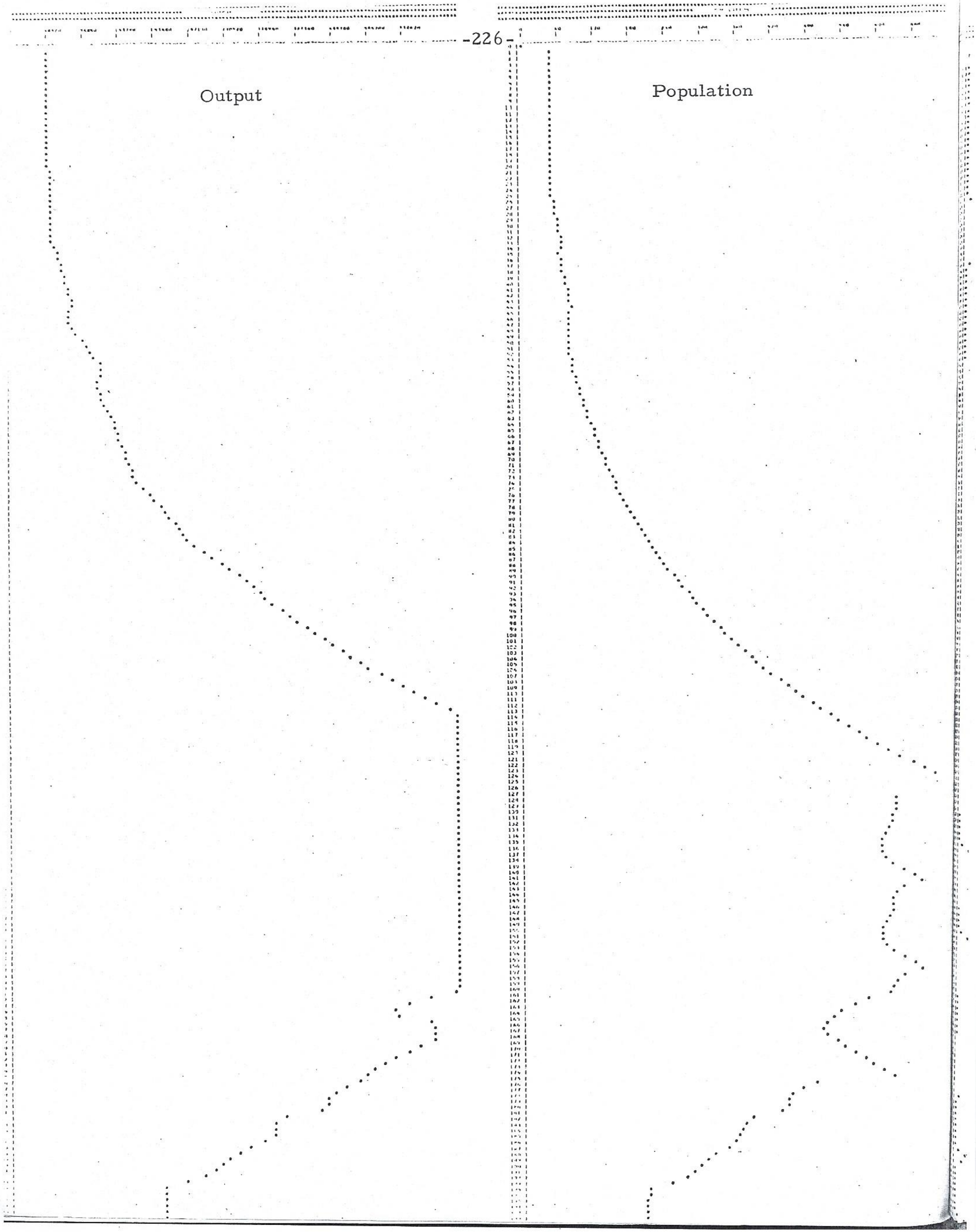
SAMPLE OUTPUT OF THE SIMULATION

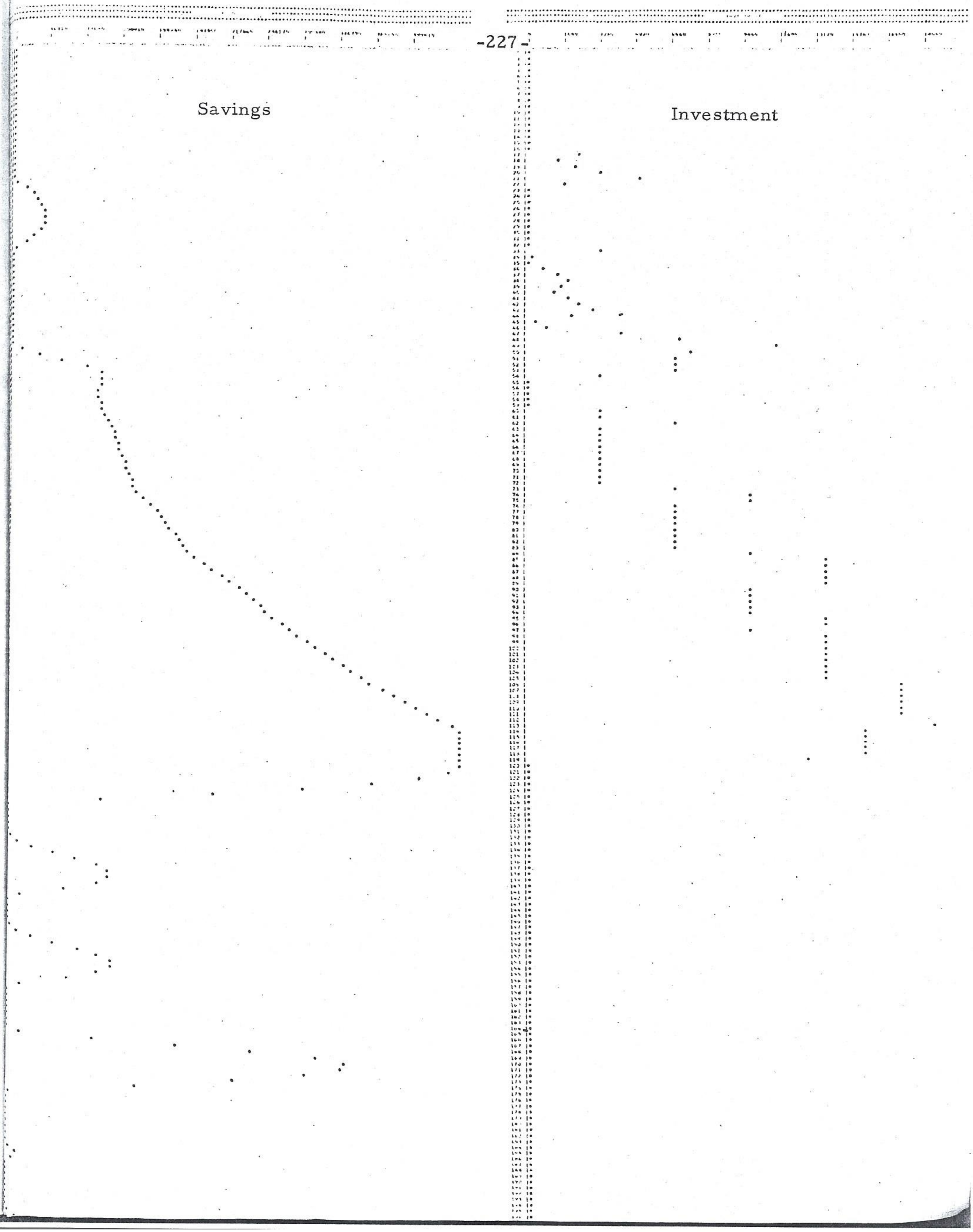
```
STANFORD ALGOL W (25 MAR 73)          ECONOMIC GROWTH SIMULATION KWK         07 JUNE 1973 @ 22:46          PAGE   1

0242 --    COMMENT +++++ INIT ALL VARIABLES TO BEGIN IN STABLE STATE +++++;          313.
0242 --    COMMENT +++++ ENERGY  IS IN UNITS OF 10**6 CALS +++++;                    314.
0242 --                                                                              314.5
0242 --    COMMENT ::: TIME_T = INTEGRAL  TIME PERIOD (YEAR):::;                     315.
0242 --       TIME_T:=0;                                                             316.
0243 --                                                                              316.5
0243 --    COMMENT ::: CUR_TECH_LEVEL = TECHNOLOGY LEVEL COUNTER:::;                 317.
0243 --       CUR_TECH_LEVEL:=1;                                                     318.
0244 --                                                                              318.5
0244 --    COMMENT ::: POPULATION = POPULATION:::;                                   319.
0244 --       POPULATION(TIME_T):=50;                                                320.
0245 --                                                                              320.5
0245 --    COMMENT ::: FRAC_WORKERS = FRACTION OF MATURE POP IN LABOR POOL:::;       321.
0245 --       FRAC_WORKERS:=1/2;                                                     322.
0246 --                                                                              322.5
0246 --    COMMENT ::: BIRTHRATE = BIRTH RATE , DEATHRATE = DEATHRATE :::;           323.
0246 --       BIRTHRATE(TIME_T):=DEATHRATE(TIME_T):=.02;                             324.
0247 --                                                                              324.5
0247 --    COMMENT ::: MAX_BIRTHRATE = LARGEST BIRTH RATE POSSIBLE :::;              325.
0247 --       MAX_BIRTHRATE:=.05;                                                    326.
0248 --                                                                              326.5
0248 --    COMMENT ::: MATURE_AGE = AGE AT WHICH INDIVIDUAL JOINS LABOR POOL :::;    327.
0248 --       MATURE_AGE:=10;                                                        328.
0249 --                                                                              328.5
0249 --    COMMENT ::: OLDAGE = AVERAGE AGE OF DEATH OR RETIREMENT :::;              329.
0249 --       OLDAGE:=40;                                                            330.
0250 --                                                                              330.5
0250 --    COMMENT ::: DAY_YEAR = DAYS PER YEAR :::;                                 331.
0250 --       DAY_YEAR:=365;                                                         332.
0251 --                                                                              332.5
0251 --    COMMENT ::: WORK_HR_DAY = AVERAGE HOURS OF WORK PER DAY :::;              333.
0251 --       WORK_HR_DAY:=4;                                                        334.
0252 --                                                                              334.5
0252 --    COMMENT ::: WORKER_OUTPUT_ENERGY = ANNUAL WORK ENERGY PER WORKER :::;     335.
0252 --       WORKER_OUTPUT_ENERGY:=ROUND(.170*WORK_HR_DAY*DAY_YEAR);                336.
0253 --                                                                              336.5
0253 --    COMMENT ::: SEDENTARY_ENERGY = ANNUAL NONWORK ENERGY CONSUMED PER         337.
0253 --           INDIVIDUAL :::;                                                    338.
0253 --       SEDENTARY_ENERGY:=ROUND(2.0*DAY_YEAR);                                 339.
0254 --                                                                              339.5
0254 --    COMMENT ::: PROPENSITY_TO_ENERGY = PROBABILITY OF AN INNOVATION           340.
0254 --           IN ANY EQUILIBRIUM YEAR :::;                                       341.
0254 --       PROPENSITY_TO_INNOVATE:=.02  ;                                         342.
0255 --                                                                              342.5
0255 --    COMMENT ::: STAGNANT = % GROWTH DEEMED EQUILIBRIUM :::;                   345.
0255 --       STAGNANT:=.01;                                                         346.
0256 --                                                                              346.5
0256 --    COMMENT ::: CAPITAL_INCR_FACTOR = INVESTMENT INCREASE FACTOR REQ          347.
0256 --          OVER INNOVATION INCREASE FACTOR :::;                                348.
0256 --       CAPITAL_INCR_FACTOR:=1.5;                                              349.
0257 --                                                                              349.5
0257 --    COMMENT ::: MAX_TECH_INNOVATION = MAX FRAC OF TECH WHICH CAN BE           350.
0257 --           ADDED TO CURRENT TECH BY AN INNOVATION ::: ;                       351.
0257 --       MAX_TECH_INNOVATION:=.20;                                              352.
0258 --                                                                              352.5
0258 --    COMMENT ::: RESOURCE_UTILIZ = FRAC OF RESOURCE POTENTIAL WHICH CAN BE     353.
0258 --           CONVERTED TO USEFUL ENERGY BY POPULATION :::;                      354.
0258 --       RESOURCE_UTILIZ(CUR_TECH_LEVEL):=.05;                                  355.
```

cussed in this paper. First, Schumpeter's model, then an adaption of

```
0259 --
0259 --    COMMENT ::: MAX_RESOURCE_EXPANSION = MAX FRAC OF (1-RES UTILIZ)
0259 --        WHICH CAN BE ADDED TO  CURRENT RES UTILIZ BY INNOV ::;
0259 --      MAX_RESOURCE_EXPANSION:= .02;
0260 --
0260 --    COMMENT ::: RESOURCE_POTENTIAL = ANNUAL ENERGY PROD OF POPULATION
0260 --        AREA ::;
0260 --      RESOURCE_POTENTIAL:=12200000;
0261 --
0261 --    COMMENT ::: INVEST_PER_RES = FRACTION OF RESOURCE CAP REQ AS
0261 --        INVESTMENT FOR UTILIZ OF TECHNOLOGY LEVEL ::;
0261 --      INVEST_PER_RES(CUR_TECH_LEVEL):=1;
0262 --
0262 --    COMMENT ::: Q0 = NUMBER TO START RANDOM SEQUENCE ::;
0262 --      Q0:=34305;
0263 --
0263 --    COMMENT ::: LABOR_POOL = # OF WORKERS IN POPULATION ::;
0263 --      LABOR_POOL(TIME_T):=ROUND((OLDAGE-MATURE_AGE)/OLDAGE*FRAC_WORKERS*
0263 --        POPULATION(TIME_T));
0264 --
0264 --    COMMENT ::: BIRTHS = # OF BIRTHS AT TIME PERIOD ::;
0264 --     FOR A:=(-OLDAGE-1) UNTIL 0  DO BIRTHS(A):=ROUND(POPULATION(TIME_T)*
0264 --        BIRTHRATE(TIME_T));
0265 --
0265 --    COMMENT ::: DEATHS = # OF DEATHS AT TIME PERIOD ::;
0265 --      DEATHS(TIME_T):= ROUND(POPULATION(TIME_T)*DEATHRATE(TIME_T));
0266 --
0266 --    COMMENT ::: HUMAN_SUBSISTENCE_ENERGY = ANNUAL ENERGY REQ PER
0266 --      INDIVIDUAL ::;
0266 --      HUMAN_SUBSISTENCE_ENERGY:=SEDENTARY_ENERGY+WORKER_OUTPUT_ENERGY;
0267 --
0267 --    COMMENT ::: TECHNOLOGY = RATIO OUTPUT/INPUT ENERGY ::;
0267 --      TECHNOLOGY(CUR_TECH_LEVEL):=(POPULATION(TIME_T)*
0267 --       HUMAN_SUBSISTENCE_ENERGY) / (LABOR_POOL(TIME_T)*
0267 --       WORKER_OUTPUT_ENERGY);
0268 --
0268 --    COMMENT ::: RESOURCE_CAPACITY = USEABLE RESOURCE ENERGY AT CUR
0268 --      UTILIZATION LEVEL ::;
0268 --       RESOURCE_CAPACITY(CUR_TECH_LEVEL):=ROUND(RESOURCE_POTENTIAL*
0268 --        RESOURCE_UTILIZ(CUR_TECH_LEVEL));
0269 --
0269 --    COMMENT ::: INVESTMENT_LEVEL = FRAC OF TOTAL RESOURCE AREA ON
0269 --      WHICH INVESTMENT TO THIS TECH LEVEL HAS BEEN MADE ::;
0269 --       INVESTMENT_LEVEL(CUR_TECH_LEVEL):=1;
0270 --
0270 --    COMMENT ::: LABOR_ENERGY = TOTAL ANNUAL LABOR ENERGY EXPENDED
0270 --      BY THE POPULATION ::;
0270 --      LABOR_ENERGY(TIME_T):=LABOR_POOL(TIME_T)*WORKER_OUTPUT_ENERGY;
0271 --
0271 --    COMMENT ::: INVESTED_ENERGY = TOTAL ENERGY INVESTED IN
0271 --      TECH LEVEL ::;
0271 --      INVESTED_ENERGY(CUR_TECH_LEVEL):=MIN(ROUND(LABOR_ENERGY(TIME_T)*
0271 --       TECHNOLOGY(CUR_TECH_LEVEL)*INVEST_PER_RES(CUR_TECH_LEVEL)),ROUND(
0271 --       RESOURCE_CAPACITY(CUR_TECH_LEVEL)*INVEST_PER_RES(CUR_TECH_LEVEL)))
0271 --        ;
0272 --    COMMENT ::: OUTPUT = PRODUCED ENERGY IN TIME PERIOD ::;
0272 --      OUTPUT(TIME_T):=ROUND(LABOR_ENERGY(TIME_T)*
0272 --        TECHNOLOGY(CUR_TECH_LEVEL));
```

```
STANFORD ALGOL W (25MAR73)                ECONOMIC GROWTH SIMULATION KWK         07 JUNE 1973  @  22:46          PAGE   3

0273 --                                                                              400.5
0273 --       COMMENT ::: MAX_SAVINGS_FRAC = PART OF OUTPUT WHICH MAY BE SAVED :::   400.6
0273 --          MAX_SAVINGS_FRAC:=.75;                                              400.7
0274 --                                                                              400.8
0274 --       COMMENT ::: SAVINGS_LIMIT = ENERGY RESERVE MAINTAINED BY POP :::       401.
0274 --          SAVINGS_LIMIT:=ROUND(OUTPUT(TIME_T)*.05);                           402.
0275 --                                                                              402.5
0275 --       COMMENT ::: SAVINGS = ACCUMULATED SAVED (NOT INVESTED) ENERGY :::      403.
0275 --          SAVINGS(TIME_T):=SAVINGS_LIMIT;                                     404.
0276 --                                                                              404.5
0276 --       COMMENT ::: INVESTMENT = INVESTMENT MADE THIS TIME PERIOD :::          405.
0276 --          INVESTMENT(TIME_T):=0;                                              406.
0277 --                                                                              406.5
0277 --       COMMENT ::: STARVATIONS = # OF INDIVIDUALS WHO STARVED THIS            407.
0277 --          TIME PERIOD :::                                                     408.
0277 --          STARVATIONS(TIME_T):=0;                                             409.
0278 --                                                                              409.5
0278 --       COMMENT ::: ADJUSTMENT = BIRTHRATE ADJUSTMENT FACTOR :::               410.
0278 --          FOR A:=TIME_T-MATUFF_AGE+1 UNTIL TIME_T DO                          411.
0278 --             ADJUSTMENT(A):=0;                                                412.
0279 --                                                                              412.5
0279 --       COMMENT ::: SURPLUS = PRODUCTION - SUBSISTENCE CONSUMPTION :::         413.
0279 --          SURPLUS(TIME_T):=0;                                                 414.
0280 --                                                                              414.5
0280 --          TIME_T:=1;                                                          415.
0281 --                                                                              415.5
0281 -3      END INITIALIZE;                                                         416.

EXECUTION OPTIONS: DEBUG,1  TIME=20 SECONDS PAGES=30 MARGIN=72

003.41 SECONDS IN COMPILATION, (20000, 05212) BYTES OF CODE GENERATED



*****************************************************************************************************************
******************************************** TIME PERIOD  17 ****************************************************
*****************************************************************************************************************

<< INNOVATION >> NEW LEVEL ==>  12.
```


Output
Population


Savings
Investment

BIBLIOGRAPHY

Burkenroad, David. 1968. "Population Growth and Economic Change." Unpublished paper.

Clark, C. and M. Haswell. 1970. The Economics of Subsistence Culture. MacMillan St. Martins Press.

Dozier, Edward P. 1966. Hano, a Tewa Indian Community in Arizona. Holt, Rinehart and Winston.

Dutton, J.M. and W.H. Starbuck. 1971. Computer Simulation of Human Behavior. Wiley.

Flannery, Kent V. 1971. "Origins and Ecological Effects of Early Domestication in Iran and the Near East." In Struever, Prehistoric Agriculture. Natural History Press.

Harris, Marvin. 1959. "The Economy Has No Surplus?" American Anthropologist, 61. 185-199.

Higgins, Benjamin. 1968. Economic Development: Principles, Problems and Policies. W.W. Norton.

Lehrner, William. 1971. Pocket Data Book USA 1971. Department of Commerce.

McGregor, J.C. 1968. Southwestern Archaeology. University of Illinois.

Rappaport, Roy A. 1969. "Ritual Regulation of Environmental Relations among a New Guinea People." In A. Vayda, Environment and Cultural Behavior. Natural History Press.

Schiffer, M.B. 1968. "The Relationship between Economic Diversity and Population Growth: The Test of an Hypothesis." Unpublished paper.

Sites, Richard L. 1972. ALGOL W Reference Manual. Stanford Computer Science Department.

Zubrow, E.B.W. 1969. Population Contact and Climate in the New Mexican Pueblos. (Now in press, University of Arizona Press.)

Zubrow, E.B.W. 1971a. "Carrying Capacity and Dynamic Equilibrium in the Prehistoric Southwest." American Antiquity, 36.2. 127-138.

Zubrow, E.B.W. 1971b. A Southwestern Test of a Model of Population Dynamics. Ph. D. dissertation, University of Arizona.

Zubrow, E.B.W. 1973a. "An Archaeological Test of Economic Growth Models." Proposal to the National Science Foundation.

Zubrow, E.B.W. 1973b. "Stability and Instability in the Problem of Regional Growth." Unpublished paper.

Output Population